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MODIFICATIONS AND IMPROVEMENTS TO THE BRLHELP CODE

Joseph F. Lacetera

June 1981

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
BALLISTIC RESEARCH LABORATORY
ABERDEEN PROVING GROUND, MARYLAND

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Input to the BRLHELP code has been changed to NAMELIST format. A previous fatal condition, overemptying of pure cells, has been converted to a non-fatal condition. Pressure iteration failure for mixed cells has been eliminated by employment of a mass-weighted average pressure scheme. A call to the BRLEOS code has been installed in the old EQST subroutine to allow access to a variety of equations of state including BRLGRAY which provides temperature as an output variable. A problem with the FORTRAN compiler on the BRL Cyber 176 is circumvented. UPDATE modifications are listed, code input is discussed, and a sample calculation is given.

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1. INTRODUCTION

The work reported here was done at the Ballistic Modeling Division of the Ballistic Research Laboratory, (BRL) in support of theoretical and experimental efforts througout the BRL. The objective of this work was the refinement and maintenance of the Eulerian, hydrodynamics code, BRLHELP[1], at the state of the art, for application to problems in both basic research and experimental studies. This objective was approached through the analysis of calculations of problems of current interest, and of the applicability of various models in BRLHELP to these problems.

The HELP[2] code, an evolutionary antecedent of BRLHELP, has been used, for some time, as a predictive tool in warhead mechanics, and intermediate and terminal ballistics. Its use is limited, however, by serious problems with the accuracy and robustness of some of its models. BRLHELP is devoid of most, if not all, of these problems. It has been modified to calculate internal energy accurately[3], has more robust treatments of certain numerical problems inherent in the old HELP code, and has temperature available as an output variable for metals and alloys via the BRLGRAY[4] equation of state.

2. BRIEF DESCRIPTION OF MODELS

Detailed descriptions of the mathematical and numerical models in BRLHELP can be found in References 1-3. A brief description is given here.

BRLHELP is a two-dimensional, Eulerian hydrodynamics code. It describes unsteady multi-material problems, treats material strength as an elastic-plastic phenomenon, and incorporates a multiphase EOS for metals.

The code uses massless tracer particles to define material interfaces and free surfaces. These particles are placed along surface boundaries and move with the local material velocity. This Lagrangian-like description provides an accurate definition of the material interfaces and free surfaces without sacrificing the ease of treatment of extreme distortion by the Eulerian model.

Input to the code consists of an initial geometric configuration, initial values, explosive loading parameters, material properties, and desired editing features.

The geometry package can describe any configuration decomposable into straight lines, arcs of circles, and arcs of ellipses. The high-explosive detonation model can treat multiple explosives, multiple detonation points, and the presence of wave shaping devices. Sliplines may be employed at material interfaces to allow different materials to develop velocities commensurate with their material properties, rather than a common interface velocity.

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1. Joseph Lacetera, Janet E. Lacetera, James A. Schmitt, "The BRL 7600 Version of the HELP Code" Ballistic Research Laboratories Report: ARBRL-TR-02209, Jan 80. (AD #A082804)

2. Laura J. Hageman, et al., "HELP, A Multi-material Eulerian Program for Compressible Fluid and Elastic-Plastic Flows in Two Space Dimensions and Time", Systems, Science, and Software Report TR-76-45-BK2, Apr 1976.

3. James A. Schmitt, "Truncation Error Terms in the Kinetic Energy Calculation in the HELP Algorithm and Their Consequences", J. Comp. Phys, Vol 35, No 2, Apr 1980.

4. Joseph Lacetera "BRLGRAY: The Ballistic Research Laboratory Version of the GRAY Equation of State", ARBRL-TR-02258, Aug 1980. (AD #A091246)

Output includes pressure, density, material velocity vectors, specific internal energy, and deviatoric stress components as functions of space and time. Temperature of metals and alloys is also available when BRLGRAY is chosen as the equation of state.

3. APPLICATIONS

BRLHELP is a necessary numerical tool for the performance of optimization and prefabrication studies for materials and geometries proposed in shaped-charge warhead design. It has the capability of modelling the collapse of the liner and the formation and development of the jet and the slug. It provides information which can be used to determine jet-tip velocity, collapse velocity and collapse angle, liner position as a function of time, stretching rate of the jet, and strength effects.

The HELP code had been used with success in predicting jet-tip velocities and liner collapse for a variety of geometric designs[5–7]. However, HELP overestimated the internal energy in the collapsed portion of conical shaped-charge liner materials. This overestimation led, in some cases, to unreasonably low estimates of jet densities[5]. Because of this an artificial bound on the internal energy in metals in shaped charge problems was installed in the Tillotson[8] EOS in an attempt to maintain a more appropriate jet density. Without this bound, the jet tip exhibited internal energies so high and densities so low as to imply vaporization.

In BRLHELP, these problems have been alleviated. Internal energies are calculated quite accurately, and the artificial bound on internal energy in metals in shaped-charge liner problems has been removed. Calculations are performed without artificial constructs and physically reasonable results are being obtained, including experimentally verifiable metal temperatures.

4. UPDATED VERSIONS OF THE BRLHELP CODE

All of the input to BRLHELP, except for an alphanumeric header card, has been converted to the NAMELIST format.

The NAMELIST input streams are called:

OPTNS, START, RUN, GRID, MTRL, GEOM, SLIP, and DETN.

In the HELP code input variables located in the first 150 words of blank common are called Z-variables because they follow Z(1), the first word of blank common, and therefore can be referenced as Z(I). A set of control parameters are first read using the NAMELIST: OPTNS. The Z-variables are then read using the NAMELISTs: START and RUN.

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5. J. T. Harrison, "Comparison Between the Eulerian Hydrodynamic Computer Code (BRLSC) and Experimental Collapse of a Shaped Charge Liner", BRL Memorandum Report ARBRL-MR-02841, Jun 1978 (AD #059711).

6. Janet E. Lacetera and William P. Walters, "Theoretical and Experimental Studies of Hemispherical Shaped-Charge Liners", Transactions of the 25th Conference of Army Mathematicians, ARO Report 80-1, Jan 1980.

7. A. Kiwan, and A. Arbuckle, "Study of Liner Collapse, Jet Formation and Characteristics from Impulsive Shaped-Charge Systems", BRL Report No. 2028, Nov 1977 (AD #051342).

8. J. H. Tillotson, "Metallic Equation of State for Hypervelocity Impacts", General Atomic Report No. GS-3216, Jul 1962.

The fatal error caused by pure cells overemptying has been corrected using coding generated by Janet Lacetera[9]. This coding is discussed in Section 6 of this report. Pressure iteration problems, inherent in old versions of the code, are discussed in Section 7 and a new mass-weighted average pressure scheme is discussed in Section 8. A call to a subroutine called BRLEOS has been installed in the old subroutine EQST, in place of equation-of-state coding, to allow access to the BRLEOS code system[10] which includes BRLGRAY, the three-phase EOS for metals.

There have been several versions of BRLHELP active on the BRL 7600. They are cycles 14 through 23 of the permanent file BRLHELP, with ID=CMCHYDRO. They differ as follows:

CY=14 BRL 7600 version of UNIVAC-1108 HELP[2].
CY=15 Cycle 14 modified for accurate energy calculation[3].
CY=16 Cycle 14 with complete NAMELIST input.
CY=17 Cycle 15 with complete NAMELIST input.
CY=18 Cycle 17 with OVERMT correction and temporary pressure iteration correction.
CY=19 Cycle 18 with FTN compiler modification.
CY=20 Cycle 19 with mass-weighted average pressure for mixed cells.
CY=21 Cycle 20 with most of EQST functions transferred to BRLEOS
CY=22 Cycle 21 with remaining EQST functions added to BRLEOS.
CY=23 Cycle 22 with temperature map for metals.

Cycles 14 through 22 have been retired.

A listing of the jobstream which created cycle 17 of BRLHELP, after cycle 16 had been created, is shown in Reference 1. Listings showing the jobstreams for creating later cycles are shown in Appendix A of this report.

5. DISCUSSION OF INPUT

A. *Capabilities and Limitations*

The problem generator allows the user to generate material interfaces which are composed of straight line segments, or portions of circles or ellipses, with the following limitations:

1. The number of material packages in a calculation is limited only by the dimensions of the material arrays.

2. A single cell can contain any number of material interfaces and any number of distinct materials.

3. Different material packages can contain the same material with different initial conditions (velocities, energies, densities).

4. A package can be divided into any number of spatially distinct subpackages.

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9. Janet Lacetera, Ballistic Research Laboratory, Aberdeen Proving Ground Private communication

10. Joseph Lacetera and William Buchheister, "BRLPUFF and the BRLEOS Code System", Ballistic Research Laboratory Interim Memorandum Report No. 655, Aug 1979.

5. The material in each package must be homogeneous.

6. The grid boundaries do not act as free surfaces. The code assumes that a package that extends to the edge of the grid is infinite in that direction.

7. The grid must have at least three rows and/or columns.

8. A calculation can be made in cylindrical or rectangular coordinates.

9. The top and right grid boundaries are transmittive. The left boundary is reflective (z-axis in cylindrical coordinates). The bottom boundary can be either transmittive or reflective.

B. *Edit Control Parameters and Z-Variables*

Edit control parameters are read using the NAMELIST: OPTNS. The Z-variables are then read using the NAMELISTS: START and RUN. These are defined below.

NAMELIST OPTNS: (Edit control parameters; it should be noted that the first three of these parameters suppress diagnostic print and should be used with caution.)

IFLGST:	=0,	default
	=1,	suppresses message "SUM OF FRACS NOT EQUAL TO TOTAL..."
IPMADJ:	=0,	default
	=1,	suppresses message "EVACUATION OF MATERIAL N..."
ITPHSE:	=0,	default
	=1,	suppresses message "MASS EVAPORATED DUE TO ROUNDOFF..."
NPRTOP:	=0,	default
	=1,	suppresses edit of sliplines
	=2,	suppresses long edit on last cycle
	=3,	combines effects of (1) and (2).
TIMMAX:		The maximum time in CPU seconds (decimal) that the code will use in the calculation. For NPRTOP =2 or 3 TIMMAX should be about 4 seconds less than the jobcard time; otherwise TIMMAX should be about 10 seconds less than the jobcard time.

NAMELIST START

PK(1): Problem identifier (numeric)

PK(2): Restart cycle number

PK(3): = 0 for startup run;
=-1 for restart without short edit print of restart cycle;
=-2 for restart with short edit print of restart cycle.

NAMELIST RUN

Contains all Z-variables not contained in NAMELIST START.

C. *Cell Dimensions*

Input data which define cell dimensions are read into NAMELIST GRID. Dimensions of cells, in the area of interest, should not vary by more than 10%, nor should large aspect ratios (e.g. dx/dy > 2) be used near the region of interest.

D.

Initial Conditions

In order for the material tracer particle routine to function, the flag of the cell in the bottom left corner of the grid, MFLAG(2), and the material code number must be defined. If the cell is a pure cell of material N, set MFLAG(2)=N; if it will be an interface, then set MFLAG(2)=-1; if it will be a void cell, set MFLAG(2)=0. (In the case of MFLAG(2)=-1 its value will be set > 100 after the interfaces are processed by CALFRC and VOLFND.)

MFLAG(2), material code numbers (listed in EQST), internal energy (ergs/gm), and radial and axial velocities (cm/s) are all read into NAMELIST MTRL. The equation-of-state constants are defined in EQST and COMDIM. Variations to the initial conditions would require modifications to FILGRD. The initial density RHOIN may be different than the material's normal density RHOZ, defined in COMDIM.

E. *Strength Constants*

Shear yield strength and tensile strength of each material package are also read into NAMELIST MTRL. If a material has no strength, AMDM(N) must be set to 1; the shear yield strength constants will be set to zero automatically if not read into MTRL.

F. *Material Tracer Particles*

Material package boundaries are described by a series of straight lines and/or arcs of cirles, and/or arcs of ellipses. Input is read by TSETUP into NAMELIST GEOM, and is defined below. Data is read into GEOM for each segment, and is read in an order that places the package to the left of the segment. Tracer particles are not placed along package boundaries that are also grid boundaries.

LT: = 1 straight horizontal line;
= 2 straight vertical line;
= 3 straight diagonal line;
= 4 arc of circle
= 5 arc of ellipse

(LT must be negative for last segment of a package or subpackage;
LT must equal 100 after all boundaries have been defined.)

MPN: Material package number (void = NMAT + 1)
NPTS: Number of points to be placed along line or arc

X1S: starting X-coordinate
Y1S: starting Y-coordinate
X2F: final X-coordinate
Y2f: final Y-coordinate
TH1: starting angle of arc
TH2: terminal angle of arc
SLA: X-coordinate of center of circle; or eccentricity parameter A in equation of ellipse
SLB: Y-coordinate of center of circle; or eccentricity parameter B in equation of ellipse
XCEN: X_c in equation of ellipse
YCEN: Y_c in equation of ellipse
XR: radius of circle

Equation of ellipse:

$$\frac{X - X_c^2}{A^2} + \frac{Y - Y_c^2}{B^2} = 1$$

An arc which begins parallel to the positive X-axis and ends parallel to the positive Y-axis has a starting angle of 3.14159 and a terminal angle of 1.57080.

LT < 0 signals TSETUP to generate a dummy tracer particle with coordinates (-1000,0) to mark the end of a tracer string for a package or subpackage.

The segments must form a continuous boundary except where they intersect the grid boundaries. Note also that each interface is described by two identical sets of tracer particles, so the number of tracers specified along an interface must be the same for each package although generated in opposite directions.

Generally, there should be at least two tracers per cell edge. In regions of great distortion tracer particles may become sparse; however, activating ADDTCR (see Z-variable NADD) helps to ensure that the tracer particles do not become too sparse. The Z-variable NTPMX limits the number of tracers for a given package boundary. NTPMX should equal the sum of the tracer particle arrays TX and TY.

G. *Slipline Endpoints*

If sliplines are being generated (NOSLIP=0) SETUP reads data defining slipline endpoints into NAMELIST SLIP. Each material is specified as a master, slave, or neither. All of the SLIP variables can be read in a single SLIP stream. These variables are defined below.

MASTRD	= N if package (of material N) is a master
	= 0 if package is a slave
NSLAVD	= N if package is a slave
	= 0 if package is a master
NBGMD	= index of first tracer particle of the slipline for master
	= 0 for slave
NBGSD	= 0 for master
	= index of first tracer particle of the slipline for slave
NENDMD	= index of last tracer particle of the slipline for master
	= 0 for slave
NENDSD	= 0 for master
	= index of last tracer particle of the slipline for slave

Sliplines can be redefined on a restart, with NOSLIP=0; otherwise, set NOSLIP=1 on the restart.

H. *High Explosive Detonation Points*

SETUP reads data defining primary and secondary initiation points into NAMELIST DETN. These are defined below.

IDET	= 1 for primary initiation point
	= 2 for secondary initiation point
	= 0 for end of initiation point data
NDETS	= material package number of high explosive
XDETS	= X-coordinate of initiation point
YDETS	= Y-coordinate of initiation point
TIME	= delay time if any
XMIN	= left X-coordinate of search area
YMIN	= lower Y-coordinate of search area
XMAX	= right X-coordinate of search area
YMAX	= upper Y-coordinate of search area

The first five of these variables are read into DETN once for each initiation point. TIME corresponds to the delay time if any for primary initiation points. The secondary points must be read in the order in which detonation will occur. The remaining variables are read into DETN once for each detonation point to define a search area for the code to determine detonation times.

A card: $DETN IDET=0$ must be read in problems without explosives.

I. *Restarts*

Restarts require only the NAMELIST's OPTNS, START, and RUN unless NOSLIP=0 in which case NAMELIST SLIP is also read.

On restarts NAMELIST RUN allows the user to redefine any of the Z-block variables. However, on runs which terminated on TIMMAX it may not be neccessary to change any variable including TSTOP or ICSTOP, depending on whether the specified values were reached during the previous run.

6. PURE CELLS OVEREMPTYING

Subroutine TPHASE determines whether a pure cell has overemptied by checking the sign of the variable AMX(K), where AMX(K) is the total mass in the Kth cell. Previously, a negative value of AMX would trigger an error exit. The current coding conserves mass locally while setting the mass of the Kth cell to zero. Thus the code is allowed to continue in the case where the overemptying is caused by small numerical error during a stretching condition.

In anticipation of some other problem causing the overemptying, a diagnostic message is printed at the time of the recovery.

The modification (IDENT OVERMT) is shown as part of the UPDATE input stream in Appendix A.

7. PRESSURE ITERATION PROBLEMS IN OLD VERSIONS OF HELP

For cells containing more than one material, the old HELP code determined cell pressure by an iteration procedure. The densities of the separate materials in such a cell were varied, with specific internal energy held constant, until the partial pressures converged to a common value. The procedure was divided into a pre-iteration calculation, to ensure that the cell was filled exactly, followed by the iteration calculation.

For the mixed cell it was required that the partial pressures satisfy

$$P_i(\rho_i, V_i) = P(\rho, V)$$

where $P(\rho,V)$ is the cell pressure.

In the iteration process, the V_i were varied until the P_i were within a specified tolerance of a common pressure.

Unfortunately, the pressure iteration routine often failed to converge in cases where the component material pressures were initially approximately equal, but the relative cell volumes were quite different.

One reason why the convergence routine failed is that the JWL[11] EOS has a pressure maximum which is potentially hazardous to such a pressure iteration. The EOS may be called during the iteration process with a pressure above this maximum. Such an occurrence would cause failure to converge. To avoid this, the variable RHOMAX was defined in a DATA statement in subroutine CDT as the maximum density to be allowed for an HE during the pressure iteration. (RHOMAX=9 for Comp B.) However, this procedure itself often caused the convergence routine to fail.

Temporary coding allowed recovery by restoration of the initial values of masses and pressures in the component materials. The values for the material which occupied the largest volume in the cell were then taken as the mixed cell values. Consequently, a warning message was printed indicating pressure iteration failure and recovery. Material pressures for each material, before and after the iteration attempt, were also printed. This coding allowed the study of mixed-cell conditions which led to pressure iteration failure.

Table 1 shows output from an actual calculation in which the pressure-iteration failure recovery was invoked. Pressures, before and after iteration, are shown for three consecutive calculational cycles. The pressures for each material are approximately equal before iteration, and pressures and densities for one or both materials are varied, with the pressures diverging during the iteration process.

TABLE 1
Pressure Iteration Failure Recovery Data

CY	ρ_1	P_1	ρ_2	P_2	ρ_1/ρ_2
1055	115.9	2.25E+14	8.66	2.24E+14	13.38
	121.9	2.49E+14	8.66	2.24E+14	
1056	115.8	2.25E+14	8.66	2.24E+14	13.37
	127.9	2.75E+14	9.56	2.47E+14	
1057	115.8	2.25E+14	8.66	2.23E+14	13.37
	133.8	3.01E+14	8.66	2.23E+14	

11. E. Lee, M. Finger, and W. Collins, "JWL Equation of State Coefficients for High Explosives", Lawrence Livermore Laboratory, UCID-16189, Jan 1973.

Table 2 shows the masses and mass ratios, at 5 cycle intervals, for the two materials. During the period shown, material 1 is passing out of the zone and material 2 is occupying an increasing portion of the total cell volume.

TABLE 2
Masses and Mass Ratios in Mixed Cells

CY	m_1	m_2	m_1/m_2
1055	6.67E-04	8.59E-02	7.76E-03
1060	5.42E-04	1.06E-01	5.11E-03
1065	4.04E-04	1.25E-01	3.23E-03
1070	2.68E-04	1.42E-01	1.89E-03
1075	1.10E-04	1.51E-01	7.28E-04
1080	6.50E-05	1.54E-01	4.22E-04
1085	3.34E-05	1.55E-01	2.15E-04
1090	3.86E-06	1.55E-01	2.49E-05

Clearly, the initial pressure of material 2 at the beginning of the process is, to a good approximation, the correct mixed-cell pressure. First, the two material pressures are approximately equal and second, material 2 occupies a dominant portion of the cell volume. In such a case the iteration process itself is unnecessary to perform. Furthermore, it is apparent from the extremely high densities of material 1 that the iteration construct had been driving the material densities to unphysical values, well before the failure to converge had indicated a problem.

Further studies with 3-material mixed cells led to the conclusion that a mass-weighted average pressure for mixed cells was the more efficient approach. The coding which invokes the new average pressure calculation is discussed in the next section.

8. MASS-WEIGHTED AVERAGE PRESSURE FOR MIXED CELLS

Before calculating an average pressure for a mixed cell, a cell filling calculation is necessary because, in general, the masses at the beginning of the calculation, do not exactly fill the cell since cell masses are changed in the TPHASE portion of the previous calculational cycle.

The code computes component material pressures P_i from component densities ρ_i while holding the specific internal energies E_i constant. The ρ_i are then varied by one percent to compute new P_i and constant energy compressibilities:

$$C_i^2 = \frac{\Delta P_i}{\Delta \rho_i}.$$

New volumes are calculated using

$$\Delta V_i = -\frac{\Delta P}{\rho_i^2 C_i^2}$$

The ρ_i are then equated to $1/V_i$ where the total cell volume is

$$V = \Sigma V_i$$

After the cell filling, the mass-weighted average cell pressures are computed directly from

$$P = \frac{P_S}{W_S}$$

where

$$P_S = \sum P_i m_i$$

and

$$W_s = \sum m_i$$

where the m_i are component masses.

9. FTN COMPILER ERROR

The current FTN OPT1 compiler at the BRL computer site does not treat certain NAMELIST variable addresses correctly. Apparently, certain three letter variable addresses are not known to have the same address by the NAMELIST package and the rest of the code. In particular, values of the parameters RMU(I), the rigidity moduli of the materials, the UUR(I), initial radial (or x) velocities, and VVA(I), initial axial (or y) velocities, read as non-zero into the location reserved for them by NAMELIST, remained zero to the rest of the code because the variables of the same name known to the rest of the code had different addresses.

For the duration of this compiler residing on the BRL Cyber system, corrective coding (IDENT MAY80FTNE), shown in Appendix A, is neccessary for avoiding this problem.

10. BRLEOS CODE SYSTEM

In old versions of HELP the subroutine EQST performed thermodynamic calculations using the Tillotson equation of state for metals and composites, the JWL equation of state for explosives, and an ideal gas equation of state for gases.

In the new version of the code, subroutine EQST is used to initialize certain EOS data and call subroutine BRLEOS. BRLEOS includes all of the EOS coding of the old EQST plus calls to the BRLGRAY equation of state and the BRLPUFF equation of state.

Applications of the EOS's are listed in Table 3 and material index numbers are listed in Table 4.

TABLE 3
Equation of State Applications

EOS	Application	Type
BRLGRAY	Metals/Alloys	Mixed-Phase Solid-Liquid-Vapor
Tillotson	Metals/Composites	Joined Compressed-Expanded
Gamma-Law	Ideal Gas	$P=[\gamma-1]\rho E$
JWL	Explosives	$P(E,\rho)$
BRLPUFF	Metals/Phenolics	Joined Compressed-Expanded

TABLE 4
Equation-of-State Material Indices

Index	Material	EOS
1	Aluminum	
2	Iron	
3	Copper	
4	Tantalum	
5	Uranium	
6	Magnesium	
7	Berylium	
8	Titanium	
9	Tin	BRLGRAY
10	Stainless	
11	Niobium	
12	Nickel	
13	Molybdenum	
14	Lead	
15	Thorium	
16	Tungsten	
17	Gold	
18	RHA	
101	Tungsten	
102	Copper	
103	Iron	
104	Aluminum	
105	Berylium	
106	Titanium	
107	Nickel	
108	Molybdenum	
109	Thorium	
110	Lead	Tillotson
111	Ch_2	
112	Granite	
113	Andesite	
114	Wet Tuff	
115	Dry Tuff	
116	Oil Shale	
117	Dolomite	
118	Limestone	
119	Halite	
120	Ideal Gas	Gamma-Law
121	Comp B	
122	TNT	
123	Octol	
124	PBX 9404	JWL
125	LX-14-0	
126	Hivelite	
227	Aluminum	
228	Plexiglas	BRLPUFF
229	Fused Quartz	
230	Quartz Phenolic	

The EOS constants for materials 112 to 119 were given by Evans and Harlow[12] and it should be noted that the constants in the Tillotson EOS for the materials Granite and Andesite are valid only for pressures less than 150 kbar.

11. SAMPLE CALCULATION

A. *Sample Input*

The jobstream corresponding to Sample Problem 2 of Reference 1 is shown in Appendix B. As the first input card indicates, this calculation is of a copper, hemispherical liner loaded with unconfined Comp B.

After the edit control parameters and Z-variables are read, the new NAMELIST input begins. The grid that is specified has 60 by 200 square cells of .05cm dimension. The next card specifies that the cell in the bottom left corner of the grid is a pure void cell. The rest of the MTRL input specifies material 1 as copper and material 2 as Comp B.

The GEOM input begins with the specification of an arc of a circle (LT=4) bounding material 1 with 300 tracers. The starting angle is PI and the terminal angle is PI/2. The center of the circle is at (0.0,6.35) with a radius of 1.905. The next segment is a horizontal line going from (1.905,6.35) to (1.7907,6.35) with 50 tracers. The description of the liner is completed with an arc (LT=-4) of radius 1.7907 corresponding to the inner radius of the liner.

The remainder of the GEOM input bounds the Comp B charge (MPN=2) and the void (MPN=3).

In this problem a slipline is placed along the interface between the liner and the explosive. The SLIP input is straightforward. The indexing begins with the master material on the left starting with the first tracer particle of the master material, counting up to the last master tracer particle on the interface (300), counting back along the interface with the slave material on the left starting with the first slave tracer (301) and ending with the last slave tracer on the interface (600).

For this explosive configuration, both a primary and secondary detonation point are required. They are placed at (0.0,2.54) and (1.82,5.62), respectively. Zero delay time is specified in both cases. The search areas specified, for the code to calculate cell detonation times, have lower left and upper right corners: (0.0,2.54) and (2.159,6.35), and (0.0,5.59) and (2.159,6.35), respectively. Less overlap would be desirable but the computing time involved is not significant. What is important is the placement of the secondary initiation point which allows it to "shine" on the portions of the explosive not covered by the primary point.

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12. M. W. Evans and F.H. Harlow, "The Particle-in-Cell Method for Hydrodynamics Calculations", Los Alamos Scientific Laboratory Report LA-2139, Nov 1957.

B. *Sample Output*

Appendix C contains the output for Sample Problem 2 run on BRLHELP, cycle 23. The first page shown is part of the dayfile. A copy of a user-library, LIBCMC, containing the BRLEOS codes is attached, along with the main program library BRLHELP, and the MIXEDPHASEBOUNDARY data tape required by BRLGRAY. This was a short run, using 867.305 JOB seconds (corresponding to TIMMAX=900). The output was stored, for later use on a restart, on a permanent disk file called CUHEMI.

The first page of actual code output lists the edit parameters. The next page shows the problem identification (read on the header card) and the geometry package including definition of the slide-line endpoints. This is followed by a description of the explosive package on two consecutive pages. The Z-variables are printed next, followed by a general description of the problem grid.

The material in package 1, G Copper, is copper described by the BRLGRAY EOS. The material in package 2, J Comp B, is Comp B described by the JWL EOS. Next comes the strength constants and a description of the grid. This takes several pages of output concluding with the cell-coordinates of the tracer particles for each material package.

The compression map at cycle 0 shows the compression values of both the metal liner and the explosive (mixed-cells are indicated by asterisks) to have the symbolic value Z. Z in this case has the value of 1.0 where in general the value of Z is given as a range of values, for example from .980 to 1.026. The display of mixed and pure cells, shown next, shows the metal liner as material 1 and the explosive as material 2, with mixed cells denoted symbolically with the letter M. Note that the void is considered as a material for computational purposes.

The next page shown is the end of the cycle 0 printout and the beginning of the regular cyclic printout. This continues until it is time for a tape dump and printout at a specified time or cycle, or at the end of the calculation. In this case the next tape dump was at the specified time of 2.0 μs which occurred at cycle 69.

The next page shown is the pressure map at 2.0 μs. The detonation wave has not quite reached the metal liner, and the BRLGRAY EOS has not yet been called for a pressure and temperature calculation. When the shock wave does hit the liner and the EOS is called for the first time, it prints out a set of input (ESTCON) and calculated (ECONS) equation-of-state constants. This occurs during the regular cyclic printout.

The last page of output shown is the temperature map. Temperatures in the liner range symbolically from E to H, indicating temperatures from 416 to 832 degrees Kelvin. The Q's and the R occurring along the explosive/metal interface are transient values which have little effect on the calculation.

12. SUMMARY

The HELP code has been shown to be an excellent tool for shaped-charge liner optimization studies; however there have been some nagging problems for its users. Two of these have been addressed. These are the fatal errors caused by: (1) over-emptying of pure cells and (2) the failure of the pressure iteration routine to achieve convergence for certain mixed-cell situations. A cycle 23 version of BRLHELP is now available which alleviates these problems. The overemptying of pure cells has been converted to a non-fatal condition and pressure iteration failure for mixed cells has been eliminated by employment of a mass-weighted average pressure scheme.

A call to the BRLEOS code system has been installed in place of the old EQST subroutine to allow access to a variety of equations of state including BRLGRAY which provides temperature as an output variable. A problem with the Fortran compiler on the BRL Cyber 176 has been circumvented.

Input to the BRLHELP code has been changed to the NAMELIST format. Interpretation of input decks is thereby less cryptic and modifications to old decks less prone to error.

13. RECOMMENDATIONS

BRLHELP should be considered for more extensive use, at the BRL, in predictive studies. Its new capability, via BRLGRAY, to produce temperature as an output variable should prove most useful to researchers trying to determine the state of shocked materials. Its new robustness should prove the code to be especially useful in prefiring analyses, where use of the code can save considerable expense by avoiding trial and error experimentation.

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11. E. Lee, M. Finger, and W. Collins, "JWL Equation of State Coefficients for High Explosive s", Lawrence Livermore Laboratory, UCID-16189, Jan 1973.

12. M. W. Evans and F.H. Harlow, "The Particle-In-Cell Method for Hydrodynamics Calculations", Los Alamos Scientific Laboratory Report LA-2139, Nov 1957.

APPENDIX A: UPDATE LISTINGS

```
LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=17 TO CY=18
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(A,BRLHELP,CY=17,ID=CMCHYDRO)
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,CY=8,ID=CMCHYDRO)
*EOR
*IDENT OVERMT
*D TPHASE.687,TPHASE.689
C   *** IF PURE CELL OVEREMPTIED CONSERVE MASS LOCALLY ***
C   *** AND ZERO OUT OVEREMPTIED CELL.                  ***
 1000 IF (AMX(K)) 1010,1070,1015
 1010 CONTINUE
      WRITE(6,1310) I,J
      KKA=K-IMAX
      WRITE(6,1350) I,J,K,MFLAG(K),AMX(K),AIX(K),U(K),V(K),DETIM(K),
     1 MFLAG(KKA),AMX(KKA),AIX(KKA),U(KKA),V(KKA),DETIM(KKA),ETH
 1350 FORMAT(3I5,/I5,5E12.5,/I5,6E12.5)
      AMX(KKA)=AMX(KKA)-AMK(K)
      AMX(K)=0.
      GO TO 1060
*IDENT LACITERA
*I CDT.12
      DIMENSION DNSAV(4),PRSAV(4),XMSAV(4)
*I CDT.71
      DNSAV(L)=0.
      PRSAV(L)=0.
      XMSAV(L)=0.
      VMAX=0.
      PMXVL=0.
*I CDT.82
      DNSAV(L)=RHO(L,M)
      XMSAV(L)=XMASS(L,M)
*I CDT.129
      PRSAV(L)=PRS(2,L)
      IF(VMAX.GT.VOL(L)) GO TO 120
      VMAX=VOL(L)
      PMXVL=PRS(2,L)
*D CDT.246
      NK=260
      WRITE(6,560) NK
*D CDT.249,CDT.250
      GO TO 314
*I CDT.283
  301 CONTINUE
*D CDT.301
      NK=310
      WRITE(6,560) NK
*D CDT.305,CDT.306
  314 DO 315 L=1,NMAT
      XMASS(L,M)=XMSAV(L)
      DNS(1,L)=DNSAV(L)
      PRS(1,L)=PRSAV(L)
```

```
LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=17 TO CY=18
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(A,BRLHELP,CY=17,ID=CMCHYDRO)
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,CY=8,ID=CMCHYDRO)
*EOR
*IDENT OVERMT
*D TPHASE.687,TPHASE.689
C   *** IF PURE CELL OVEREMPTIED CONSERVE MASS LOCALLY ***
C   *** AND ZERO OUT OVEREMPTIED CELL.                  ***
 1000 IF (AMX(K)) 1010,1070,1015
 1010 CONTINUE
      WRITE(6,1310) I,J
      KKA=K-IMAX
      WRITE(6,1350) I,J,K,MFLAG(K),AMX(K),AIX(K),U(K),V(K),DETIM(K),
     1 MFLAG(KKA),AMX(KKA),AIX(KKA),U(KKA),V(KKA),DETIM(KKA),ETH
 1350 FORMAT(3I5,/I5,5E12.5,/I5,6E12.5)
      AMX(KKA)=AMX(KKA)-AMK(K)
      AMX(K)=0.
      GO TO 1060
*IDENT LACITERA
*I CDT.12
      DIMENSION DNSAV(4),PRSAV(4),XMSAV(4)
*I CDT.71
      DNSAV(L)=0.
      PRSAV(L)=0.
      XMSAV(L)=0.
      VMAX=0.
      PMXVL=0.
*I CDT.82
      DNSAV(L)=RHO(L,M)
      XMSAV(L)=XMASS(L,M)
*I CDT.129
      PRSAV(L)=PRS(2,L)
      IF(VMAX.GT.VOL(L)) GO TO 120
      VMAX=VOL(L)
      PMXVL=PRS(2,L)
*D CDT.246
      NK=260
      WRITE(6,560) NK
*D CDT.249,CDT.250
      GO TO 314
*I CDT.283
  301 CONTINUE
*D CDT.301
      NK=310
      WRITE(6,560) NK
*D CDT.305,CDT.306
  314 DO 315 L=1,NMAT
      XMASS(L,M)=XMSAV(L)
      DNS(1,L)=DNSAV(L)
      PRS(1,L)=PRSAV(L)
```

```
      IF(PRS(1,L).GT.PMIN) PSUM=1
  315 PAV=PMXVL
*CCPY CDT,CDT.303,CDT.304
      GO TO 301
*D CDT.439
  560 FORMAT(1H1,*PRESSURE ITERATION FAILURE,          RECOVERED AT CDT
     1 LINE NUMBER*,I5)


LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=18 TO CY=19
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(A,BRLHELP,ID=CMCHYDRO)
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,ID=CMCHYDRO,RP=999)
*EOR
*IDENT MAY80FINE
*D GEOM.7
     1         CZERO,  STK1,  STK2,  STEZ,  TEMP,  AMDM
*I GEOM.10
      DO 100 IRMU=1,4
  100 RMU(IRMU)=TEMP(IRMU)
C *** THIS CODING NECESSARY TO AVOID OPT1 COMPILER ERROR ***


LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=19 TO CY=20
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(A,BRLHELP,ID=CMCHYDRO)
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,ID=CMCHYDRO,RP=999)
*EOR
*IDENT CELLFILL
*YANK LACITERA
*D CDT.78
*D CDT.95,CDT.162
C
C     *** COMPUTE TWO DENSITIES FOR
C     *** EACH MATERIAL IN CELL USING
C     *** (1) DENSITIES FROM LAST CYCLE
C     *** (2) THOSE DENSITIES INCREASED BY ONE PERCENT
C
*COPY CDT,CDT.99,CDT.129
*COPY CDT,CDT.130,CDT.141
      IF (VL(L).GT.0) GO TO 170
      VL(L)=0.0
      XMASS(L,M)=0.0
  170 CONTINUE
```

```
*IDENT PCALC
*D CDT.163,316
*COPY CDT,CDT.163,CDT.176
*COPY CDT,CDT.184,CDT.224
C
C     *** MASS WEIGHTED AVERAGE PRESSURE
                P(K)=PSUM/WSUM
C
C
*COPY CDT,CDT.308,CDT.316
*IDENT LCTSEP80
*D INPUT.75,INPUT.76
C
      CALL SETUP
C *** ONLY TO READ SLIP LINE DATA AND RETURN ***
C
*B SETUP.13
C
C *** IF RESTART READ SLIP DATA AND RETURN ***
      IF(PK(3).LT.0) READ(5,SLIP)
      IF(PK(3).LT.0) RETURN
C
*D GEOM.6,MAY80FTNE.1
C
      NAMELIST/MTRL/   MFLAG, MAT,   RHOIN, SSIEN, UURX, VVAY,
     1         CZERO,  STK1,  STK2,  STEZ,  RMUI,  AMDM
*D MAY80FTNE.2,MAY80FTNE.4
      DO 100 I=1,4
      UUR(I)=UURX(I)
      VVA(I)=VVAY(I)
  100 RMU(I)=RMUI(I)
C *** THIS CODING NECESSARY TO AVOID OPT1 COMPILER ERRORS ***
C *** DETECTED BY JOE LACETERA DURING PERIOD MAY-SEP 1980 ***
*I SETUP.11
      DIMENSION UURX(4), VVAY(4), RMUI(4)


LCTRA,STMFZ,T100.  UPDATE TO BRLHELP; CY=20 TO CY=21
ACCOUNT(MD440)
REQUEST(NEWPL, *PF)
GETPF(OLDPL,PRLHELP,ID=CMCHYDRO)
UPDATE(F,N)
CATALOG(NEWPL,BRLHELP,ID=CMCHYDRO)
EXIT.
*EOR
*IDENT EQSTEOS
*D BRL76.6
     1 TAPE10,TAPE1)
*I EQST.6
      COMMON/EQSTEOS/XAMDM(4),XEMIN,XGAMMA,XROEPS,XMFK
*I HELPCOM.71
      LEVEL 2, PLWP,PLWC,PVOL,ALPSV
```

```
*D EQST.11,EQST.234

      XAMDM(MFK)=AMDM(MFK)
      XEMIN=EMIN
      XGAMMA=GAMMA
      XROEPS=ROEPS
      XMFK=MFK
      ENERGY=AMAX1(ENERGY,0.)
      CALL BRLEOS(ENERGY,RHOW,PRESUR,TMPTR,CS,IV,N)
*D MEMEXPND.1
      COMMON/MXCELL/ RHOZ(130),CNAUT(130),MAT(130),SAMMY(4,800),
*D INPUT.8
      DIMENSION MNAME(130)
*D HELPEQ.18,HELPEQ.36
C
C
C
C               MATERIAL PROPERTY DATA STATEMENTS
C
C               MATERIALS 1 - 18 ARE BRLGRAY EOS METALS
C
C               MATERIALS 101-119 ARE TILLOTSON MATERIALS
C
C               MATERIAL  120 IS IDEAL GAS
C
C               NOTE - IDEAL GAS REFERENCE DENSITY RHOZ(120) IS THE
C                      NORMAL DENSITY OF AIR.  THIS VALUE MUST BE
C                      CHANGED FOR OTHER GASES.
C
C               EXPLOSIVE 121 IS COMPB
C               EXPLOSIVE 122 IS TNT
C               EXPLOSIVE 123 IS OCTOL
C               EXPLOSIVE 124 IS PBX 9404
C               EXPLOSIVE 125 IS LX-14-0
C               EXPLOSIVE 126 IS HIVELITE
C
      DATA (RHOZ(K),K=1,18) /
     1      2.70,     7.87,     8.94,    16.65,    19.08,
     2      1.75,     1.85,     4.51,     7.28,     7.91,
     3      8.58,     8.86,    10.22,    11.36,    11.68,
     4     19.17,     19.24,    7.84/
      DATA (RHOZ(K),K=101,119) /
     1     19.17,     8.94,     7.87,     2.70,     1.85,
     2      4.51,     8.86,    10.22,    11.68,    11.36,
     3       .90,     2.70,     2.70,     1.97,     1.70,
     4      2.30,     2.80,     2.70,     2.20/

      DATA RHOZ(120)/.001293/

      DATA (RHOZ(K),K=121,126) /
     1     1.717,    1.630,    1.821,    1.840,     1.835,     1.89/
```

```
      DATA (CNAUT(K),K=101,119)/
     1     4.01E5,   3.95E5,   4.03E5,   5.27E5,   8.06E5,
     2     4.78E5,   4.63E5,   5.15E5,   2.13E5,   2.03E5,
     3     2.89E5,   2.58E5,   2.58E5,   2.24E5,   1.63E5,
     4     3.49E5,   5.51E5,   3.85E5,   3.37E5/

*D CDT.15,CDT.22
           GAMGAS(120) = GAMMA
      DATA (GAMGAS(K), K=121,126)/2.706,2.727,2.830,2.850,2.841,1.24/
      DATA (RHOMAX(K), K=121,126)/9.0, 8.5, 9.5, 11.0, 9.5, 9.5/
C
*D DETIME.7,DETIME.18
C
C     EXPLOSIVE 121 IS COMPB
C     EXPLOSIVE 122 IS TNT
C     EXPLOSIVE 123 IS OCTOL
C     EXPLOSIVE 124 IS PBX 9404
C     EXPLOSIVE 125 IS LX-14-0
C     EXPLOSIVE 126 IS HIVELITE
C
C     DETVEL IS THE DETONATION VELOCITY
C
      DATA DETVEL(121) /7.98E5/
      DATA DETVEL(122) /6.93E5/
      DATA DETVEL(123) /8.48E5/
      DATA DETVEL(124) /8.80E5/
      DATA DETVEL(125) /8.83E5/
      DATA DETVEL(126) /.381E5/

*D ADDENG.8,ADDENG.12
      DATA (DENGY(K),K=121,126) /
     2     4.95E+10, 3.68E+10, 5.27E+10, 5.54E+10, 1.02E+10, 4.20E+10/
C             EXPLOSIVE 121 IS COMPB
C             EXPLOSIVE 122 IS TNT
C             EXPLOSIVE 123 IS OCTOL
C             EXPLOSIVE 124 IS PBX 9404
C             EXPLOSIVE 125 IS LX-14-0
C             EXPLOSIVE 126 IS HIVELITE
*D INPUT.10,INPUT.16
      DATA (MNAME(K),K=1,18)/
     1 10HG ALUMINUM,10HG     IRON,10HG   COPPER,10HG TANTALUM,
     2 10HG  URANIUM,10HGMAGNESIUM,10HG BERYLIUM,10HG TITANIUM,
     3 10HG      TIN,10HG  S-STEEL,10HG  NIOBIUM,10HG   NICKEL,
     4 10HG     MOLY,10HG     LEAD,10HG  THORIUM,10HG TUNGSTEN,
     5 10HG     GOLD,10HG      RHA/


      DATA (MNAME(K),K=101,124)/
     1 10HT TUNGSTEN,10HT   COPPER,10HT     IRON,10HT ALUMINUM,
     2 10HT BERYLIUM,10HT TITANIUM,10HT   NICKEL,10HT     MOLY,
     3 10HT  THORIUM,10HT     LEAD,
     4 10HT POLYMERS,10HT  GRANITE,10HT ANDESITE,10HT WET TUFF,
     5 10HT DRY TUFF,10HT      OIL,10HT    SHALE,10HT DOLOMITE,
     6 10HTLIMESTONE,10HT   HALITE,10H IDEAL GAS,10HJ   COMP B,
     7 10HJ       TNT,10HJ    OCTOL,10HJ      PBX,10HJ     9404/
```

```
      DATA MNAME(125) /10HJ  LX-14-0/
      DATA MNAME(126) /10HJ HIVELITE/
*D INPUT.99,INPUT.107

C          PRINT INITIAL CONDITIONS

      WRITE(6,390)
      DO 60 L=1,NMAT
      MN=MAT(L)
      WRITE(6,400) L,RHOZ(MN),RHOIN(L),SSIEN(L),UUR(L),VVA(L),MNAME(MN)
   60 CONTINUE
*D BRL76.90
  400 FORMAT(I5,2F13.3,9X,1PE11.4,5X,1PE11.4,5X,1PE11.4,A10)
*I EDIT.240

  305 CONTINUE
*D NOEDPRT.8



LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=21 TO CY=22
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(TA,PLCMCEOS,ID=CMCeOS)
UPDATE(Q,P=TA,N=TEMPL)
GETPF(A,BRLHELP,ID=CMCHYDRO)
UPDATE(F,P=A,M=TEMPL,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,ID=CMCHYDRO,RP=999)
*EOR
*COMPILE BRLEOS
*EOR
*IDENT EQSTEOSCR
*D EQSTEOS.45,EQSTEOS.47
     5 10HT DRY TUFF,10HT OILSHALE,10HT DOLOMITE,10HTLIMESTONE,
     6 10HT   HALITE/
C
      DATA MNAME(120) /10H IDEAL GAS/
C
      DATA MNAME(121) /10HJ   COMP B/
      DATA MNAME(122) /10HJ      TNT/
      DATA MNAME(123) /10HJ    OCTOL/
      DATA MNAME(124) /10HJ PBX 9404/
*IDENT EOSDET
*D CDT.12
      DIMENSION RHOMAX(130), GAMGAS(130)
*D DETIME.5
     1DETVEL(130)
*D ADDENG.4,ADDENG.6
      DIMENSION DENGY(130)
*D DETIME.132
      IF(N.GT.120.AND.N.LT.200) GO TO 105
*D DETIME.135
  100 IF(MAT(M).LE.120.OR.MAT(M).GE.200) GO TO 120
```

```
*D DETIME.212
      IF(MAT(MFK).GT.120.AND.MAT(MFK).LT.200) GO TO 190
*D DETIME.218
      IF(MAT(L).GT.120.AND.MAT(L).LT.200) GO TO 190
*D DETIME.235
      IF(MAT(L).GT.120.AND.MAT(L).LT.200) GO TO 173
*D DETIME.245
      IF(MAT(L).GT.120.AND.MAT(L).LT.200) GO TO 176
*D DETIME.256
      IF(MAT(MFL).GT.120.AND.MAT(MFL).LT.200) GO TO 181
*D DETIME.261
      IF(MAT(L).GT.120.AND.MAT(L).LT.200) GO TO 181
*D DETIME.272
      IF(MAT(MFL).GT.120.AND.MAT(MFL).LT.200) GO TO 185
*D DETIME.276
      IF(MAT(L).GT.120.AND.MAT(L).LT.200) GO TO 185
*D DETIME.365
      IF(MAT(MFK).LE.120.OR.MAT(MFK).GE.200) GO TO 170
*D DETIME.393
      IF(MAT(L).LE.120.OR.MAT(L).GE.200) GO TO 360


LCTRA,STMFZ,T200.  UPDATE TO BRLHELP; CY=22 TO CY=23
ACCOUNT(MD440)
REQUEST(B, *PF)
GETPF(A,BRLHELP,ID=CMCHYDRO)
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
CATALOG(B,BRLHELP,ID=CMCHYDRO,RP=999)
*EOR
*IDENT GEOMCR
*D GEOM.15
   30 WRITE(6,370) X1S,YIS,X2F,Y2F
*IDENT TMPOCT80
*I HELPCOM.83
      COMMON/TGRAY/TGRAY, TXG(12000), TRS(4)
      LEVEL 2,      TGRAY, TXG,        TRS
*D EQST.3,EQST.6
C *** INITIALIZE SOME BRLGRAY PARAMETERS AND CALL BRLEOS
C
*B EQST.32
      TGRAY=0.
*I EQST.32
      TGRAY=TMPTR
*B CDT.23
      TGRAY=0
*I CDT.60
      TXG(K)=TGRAY
*I PCALC.12
      TRS(L)  =TGRAY
*I PCALC.35
      TSUM=0.
*I PCALC.54
      TSUM=AMAX1(TSUM,TRS(L))
```

```
*I PCALC.58
C
C     *** MAXIMUM TEMPERATURE FOR ANY METAL IN THE MIXED CELL
                TXG(K)=TSUM
*D MAP.7
      DIMENSION WSMAX(6), ALE(41), XUM(41), VALUE(41)
*I MAP.71
C             *** TEMPERATURE
      DO 75 J=1,JDL
      DO 75 I=1,IDL
      K=(J-1)*IMAX+I+1
      M=IABS(MFLAG(K))
      N=MAT(M)
      IF(N.GE.100) TXG(K)=0.
      IF(N.GE.100) GO TO 74
      IF(TXG(K).EQ.0) TXG(K)=300.
   74 CONTINUE
   75 WSMAX(6)=AMAX1(WSMAX(6),ABS(TXG(K)))
      PRINT *,"TMAX=",WSMAX(6)
*I MAP.139
      GO TO 230
C
C             *** TEMPERATURE
C
  225 J=JDL
      IF(WSMAX(NPROP).LE.0) GO TO 460
      WRITE(6,535) CYCLE,T
  226 DO 228 I=1,IDL
      K=(J-1)*IMAX+I+1
  228 PROP(I)=TXG(K)
*D MAP.234
      GO TO (90,120,150,180,210,226) NPROP
*D MAP.242
      GO TO (470,110,140,170,200,225,470) NPROP
*I MAP.259
  535 FORMAT(1H1,4X,15HTEMPERATURE     ,1X,6HCYCLE=,F8.1,4X,5HTIME=,
     *1PE11.5,1X,7HSECONDS//)
```

APPENDIX B: SAMPLE INPUT

```
LCTIL,STMFZ,T1000,P0.   SAMPLE PROBLEM 2: CU HEMISPHERE LACETERA
ACCOUNT(MD440)
REQUEST(TAPE7, *PF)
GETPF(LIBCMC,LIBCMC,                ID=CMCEOS)
GETPF(A,     BRLHELP,               ID=CMCHYDRO)
GETPF(TAPE1, MIXEDPHASEBOUNDARY, ID=CMCEOS)
LIBRARY(LIBCMC)
EDITLIB.
UPDATE(F,P=A,N=B)
FTN(I=COMPILE,L=0,PL=55000,LCM=I)
RFL(160000)
LGO.
CATALOG(TAPE7,CUHEMI,ID=CMCHYDRO)
EXIT.
*EOR
LISTLIB(*,LIBCMC)
*EOR
*EOR
 SAMPLE PROBLEM 2:COPPER HEMISPHERE LOADED WITH COMP B UNCONFINED
 $OPTNS NPRTOP=2,     TIMMAX=900,  IFLGST=1,  IPMADJ=1,  ITPHSE=1$
 $START PK(1)=1,        PK(2)=0,       PK(3)=-0$
 $RUN   TSTOP= 6.0E-06, PRDELT= 2.0E-06,
        KUNITW=7,       KUNITR=7,
        NOSLIP=0,       LVISC=1,
        NMAT=2,        NMXCLS=800,   NTRACR=5,  NTPMX=900,  REZ=0.,
        CYCPH3=-1,      NLINER=1,      NSLD=300,
        MAPS=1,         IMAX=60,       JMAX=200,   DMIN=100,
        IPR=100,
        NFRELP=100,     NDUMP7=1,     IPCYCL=0,   I1=3,    I2=53,
        CVIS=-1,        IGM=0$
 $GRID DX=60*.05,  DY=200*.05$
 $MTRL MFLAG(2)=0,
       MAT(1)= 3,  RHOIN(1)=8.94,
       MAT(2)= 121,  RHOIN(2)=1.717,
       CZERO(1)=2.35E+09, STK1(1)=6.95E+10, STK2(1)=5.50E+10,
       STEZ(1) =5.30E+09, RMUI(1) =4.55E+11, AMDM(1)= .9785,
                                             AMDM(2)=1.0$
```

```
$GEOM LT=4,   MPN=1,   NPTS=300,
      TH1=3.14159, TH2=1.57080,
      SLA=0.0,   SLB=6.35,   XR=1.905$
$GEOM LT=1,   MPN=1,   NPTS=50,
      X1S=1.905,   Y1S=6.35,   X2F=1.7907,   Y2F=6.35$
$GEOM LT=-4,  MPN=1,   NPTS=300,
      TH1=1.57080, TH2=3.14159,
      SLA=0.0,   SLB=6.35,   XR=1.7907$
$GEOM LT=1,   MPN=2,   NPTS=100,
      X1S=0.0,     Y1S=2.54,   X2F=2.159,    Y2F=2.54$
$GEOM LT=2,  MPN=2,   NPTS=200,
      X1S=2.159,   Y1S=2.54,   X2F=2.159,    Y2F=6.35$
$GEOM LT=1,  MPN=2,   NPTS=50,
      X1S=2.159,   Y1S=6.35,   X2F=1.905,    Y2F=6.35$
$GEOM LT=-4, MPN=2,   NPTS=300,
      TH1=1.57080,  TH2=3.14159,
      SLA=0.0,   SLB=6.35,   XR=1.905$
$GEOM LT=4, MPN=3,  NPTS=300,
      TH1=3.14159,  TH2=1.57080,
      SLA=0.0,  SLB=6.35,  XR=1.7907$
$GEOM LT=1,     MPN=3,     NPTS=50,
      X1S=1.7907, Y1S=6.35,    X2F=1.905,   Y2F=6.35$
$GEOM LT=1,      MPN=3,    NPTS=50,
      X1S=1.905,  Y1S=6.35,    X2F=2.159,   Y2F=6.35$
$GEOM LT=2,      MPN=3,    NPTS=200,
      X1S=2.159,  Y1S=6.35,    X2F=2.159,   Y2F=2.54$
$GEOM LT=-1,     MPN=3,    NPTS=100,
      X1S=2.159,  Y1S=2.54,    X2F=0.0,     Y2F=2.54$
$GEOM LT=100$
$SLIP MASTRD(1)=1,    NSLAVD(1)=0,       NBGMD(1)=1,
      NBGSD(1) =0,    NENDMD(1)=300,     NENDSD(1)=0,
      MASTRD(2)=0,    NSLAVD(2)=2,       NBGMD(2)=0,
      NBGSD(2)=301,   NENDMD(2)=0,       NENDSD(2)=600$
$DETN IDET=1,  NDETS=2,  XDETS=0.0,  YDETS=2.54, TIME=0.0$
$DETN IDET=2,  NDETS=2,  XDETS=1.82, YDETS=5.62, TIME=0.0$
$DETN IDET=0$
$DETN XMIN=0.0,  YMIN=2.54,  XMAX=2.159, YMAX=6.35$
$DETN XMIN=0.0,  YMIN=5.59,  XMAX=2.159, YMAX=6.35$
```

APPENDIX C: SAMPLE OUTPUT

```
***  10/06/80  SCOPE 2.1.5  B R L  VER 011  ***   11/06/80      80311

SYS DEVICES 919/ 4/PF FLS=377K FLL=1750K MXS=300K MXL=1305K MXB=1305B

HH.MM.SS CPU SECOND ORIGIN
         08.27.28.MFA. **     BRL NOS/BE 1.3 L499 VER 007    10/09/80
16.08.32 00000.005 MFZ.      -LCTIL,STMFZ,T1000,P0.           SAMPLE PROBLEM 2: CU HEMISPHERE LACETERA
16.08.32 00000.006 JOB.      -ACCOUNT(ID***)
16.08.33 00000.028 JOB.      -REQUEST(TAPE7, *PF)
16.08.33 00000.032 JOB.      -GETPF(LIBCMC,LIBCMC,             ID=CMCEOS)
16.08.33 00000.033 JOB.      -GETPF(A,     BRLHELP,            ID=CMCHYDRO)
16.08.33 00000.034 JOB.      -GETPF(TAPE1, MIXEDPHASEBOUNDARY, ID=CMCEOS)
16.08.33 00000.035 JOB.      -LIBRARY(LIBCMC)
16.08.33 00000.037 MFZ.        JM262 - STAGE PF ST=MFZ LFN=LIBCMC
         16.08.33 00000.003 MFZ.      -SJACP,STMFZ,T100,P7000.    ATT/CAT/PRG SPOT JOB
         16.08.33 00000.004 JOB.      -ACCOUNT(CS***) SYSTEM JOB SJACP
         16.08.34 00000.027 LOD.      -PFCONV.   CALL ATTACH/CAT/PURGE UTILITY
         16.08.34 00000.033 MFZ.         PF646 - PFMACRO - ATTACH  - LIBCMC  - LIBCMC
         16.08.34 00000.036 MFZ.         PF254 - CYCLE   10 ATTACHED FROM SN=SYSTEM
         16.08.34 00000.038 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
         16.08.34 00000.052 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
16.09.35 00000.041 LOD.      -EDITLIB.
16.09.37 00000.059 USR.        FORTRAN LIBRARY 508          05/27/80
16.09.37 00000.073 USR.           STOP
16.09.37 00000.073 USR.           042100   FINAL EXECUTION FL.
16.09.37 00000.074 USR.                .014 CP SECONDS EXECUTION TIME.
16.09.37 00000.074 LOD.      -UPDATE(F,P=A,N=B)
16.09.37 00000.088 MFZ.         JM262 - STAGE PF ST=MFZ LFN=A
         16.09.38 00000.003 MFZ.      -SJACP,STMFZ,T100,P7000.    ATT/CAT/PRG SPOT JOB
         16.09.38 00000.004 JOB.      -ACCOUNT(CS***) SYSTEM JOB SJACP
         16.09.40 00000.027 LOD.      -PFCONV.   CALL ATTACH/CAT/PURGE UTILITY
         16.09.40 00000.033 MFZ.         PF646 - PFMACRO - ATTACH  - A       - BRLHELP
         16.09.40 00000.036 MFZ.         PF254 - CYCLE   23 ATTACHED FROM SN=SYSTEM
         16.09.40 00000.038 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
         16.09.42 00000.087 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
16.10.43 00004.098 USR.        UPDATE COMPLETED
16.10.43 00004.099 LOD.      -FTN(I=COMPILE,L=0,PL=55000,LCM=I)
16.17.47 00029.455 USR.           25.347 CP SECONDS COMPILATION TIME
16.17.47 00029.456 JOB.      -RFL(160000)
16.17.50 00029.456 LOD.      -LGO.
16.25.48 00029.963 MFZ.         LD610 - FLS REQUIRED TO LOAD - 0043770 OU.COG
16.25.48 00029.966 MFZ.         LD603 - EXECUTION INITIATED OS.EXP
16.25.48 00029.966 USR.        FORTRAN LIBRARY 518          09/30/80
16.26.00 00040.586 MFZ.         JM262 - STAGE PF ST=MFZ LFN=TAPE1
         16.26.00 00000.003 MFZ.      -SJACP,STMFZ,T100,P7000.    ATT/CAT/PRG SPOT JOB
         16.26.00 00000.004 JOB.      -ACCOUNT(CS***) SYSTEM JOB SJACP
         16.26.02 00000.027 LOD.      -PFCONV.   CALL ATTACH/CAT/PURGE UTILITY
         16.26.02 00000.033 MFZ.         PF646 - PFMACRO - ATTACH  - TAPE1   - MIXEDPHASEBOUNDARY
         16.26.02 00000.036 MFZ.         PF254 - CYCLE   19 ATTACHED FROM SN=SYSTEM
         16.26.02 00000.038 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
         16.26.02 00000.045 MFZ.         JM262 - STAGE PF SPOT   LFN=PF76C
17.34.06 00897.272 USR.           EXIT
17.34.06 00897.272 USR.             160000   FINAL EXECUTION FL.
17.34.06 00897.273 USR.           867.305 CP SECONDS EXECUTION TIME.
17.34.06 00897.276 JOB.      -CATALOG(TAPE7,CUHEMI,ID=CMCHYDRO)
17.34.06 00897.281 MFZ.         PF060 - CYCLE    3 CATALOGED ON SN=SYSTEM
17.34.06 00897.282 JOB.      -EXIT.
17.34.06 00897.284 MFZ.         JM166 - MAXIMUM USER SCM         1600000B WORDS
17.34.06 00897.285 MFZ.         JM167 - MAXIMUM USER LCM         6510000B WORDS
17.34.06 00897.285 MFZ.         JM170 - MAXIMUM JS*IO LCM           2238 BUFFERS
17.34.06 00897.285 MFZ.         RM770 - MAXIMUM ACTIVE FILES                   8
17.34.06 00897.285 MFZ.         RM771 - OPEN/CLOSE CALLS                      48
17.34.06 00897.285 MFZ.         RM772 - DATA TRANSFER CALLS               193,876
17.34.06 00897.285 MFZ.         RM773 - CONTROL/POSITIONING CALLS           1,002
17.34.06 00897.286 MFZ.         RM774 - RM DATA TRANSFER CALLS             10,966
```

```
$OPTNS
IFLGST  = 1,
IPMADJ  = 1,
ITPHSE  = 1,
NPRTOP  = 2,
TIMMAX  = .9E+03,
$END
```

SAMPLE PROBLEM 2 - COPPER HEMISPHERE LOADED WITH COMP B HE UNCONFINED

```
   TYPE=   4      PACKAGE=  1     NUMBER OF POINTS=  300
 TH1=   .3141590E+01  TH2=   .1570800E+01  A=  0.              B=   .6350000E+01  R=   .1905000E+01
   TYPE=   1      PACKAGE=  1     NUMBER OF POINTS=   50
   X1=   .1905000E+01     Y1=  0.                  X2=   .1790700E+01     Y2=   .6350000E+01
   TYPE=  -4      PACKAGE=  1     NUMBER OF POINTS=  300
 TH1=   .1570800E+01  TH2=   .3141590E+01  A=  0.              B=   .6350000E+01  R=   .1790700E+01
   TYPE=   1      PACKAGE=  2     NUMBER OF POINTS=  100
   X1=  0.                Y1=  0.                  X2=   .2159000E+01     Y2=   .2540000E+01
   TYPE=   2      PACKAGE=  2     NUMBER OF POINTS=  200
   X1=   .2159000E+01     Y1=   .2540000E+01     X2=   .2159000E+01     Y2=   .6350000E+01
   TYPE=   1      PACKAGE=  2     NUMBER OF POINTS=   50
   X1=   .2159000E+01     Y1=  0.                  X2=   .1905000E+01     Y2=   .6350000E+01
   TYPE=  -4      PACKAGE=  2     NUMBER OF POINTS=  300
 TH1=   .1570800E+01  TH2=   .3141590E+01  A=  0.              B=   .6350000E+01  R=   .1905000E+01
   TYPE=   4      PACKAGE=  3     NUMBER OF POINTS=  300
 TH1=   .3141590E+01  TH2=   .1570800E+01  A=  0.              B=   .6350000E+01  R=   .1790700E+01
   TYPE=   1      PACKAGE=  3     NUMBER OF POINTS=   50
   X1=   .1790700E+01     Y1=  0.                  X2=   .1905000E+01     Y2=   .6350000E+01
   TYPE=   1      PACKAGE=  3     NUMBER OF POINTS=   50
   X1=   .1905000E+01     Y1=  0.                  X2=   .2159000E+01     Y2=   .6350000E+01
   TYPE=   2      PACKAGE=  3     NUMBER OF POINTS=  200
   X1=   .2159000E+01     Y1=   .6350000E+01     X2=   .2159000E+01     Y2=   .2540000E+01
   TYPE=  -1      PACKAGE=  3     NUMBER OF POINTS=  100
   X1=   .2159000E+01     Y1=  0.                  X2=  0.                Y2=   .2540000E+01
   TYPE= 100      PACKAGE=  3     NUMBER OF POINTS=  100
```

DEFINITION OF SLIDE ENDPOINTS

PKG. NO.	MASTER	SLAVE	NBGM	NBGS	NENDM	NENDS
1	1	0	1	0	300	0
2	0	2	0	301	0	600

DETONATION TIME CALCULATION FOR EXPLOSIVE PACKAGES

TYPE OF INITIATION POINT	1	EXPLOSIVE PACKAGE	2	INITIATION POINTS	0.	2.54000E+00	DELAY TIME	0.
TYPE OF INITIATION POINT	2	EXPLOSIVE PACKAGE	2	INITIATION POINTS	1.82000E+00	5.62000E+00	DELAY TIME	0.

SEARCH AREA XMIN 0. YMIN 2.5400000E+00 XMAX 2.1590000E+00 YMAX 6.3500000E+00
INITIATION POINT X 0. Y 2.5400000E+00 DELAY TIME 0.

DETONATION TIME FOR EACH ROW(J)

J

SEARCH AREA XMIN 0. YMIN 5.5000000E+00 XMAX 2.1590000E+00 YMAX 6.3500000E+00
INITIATION POINT X 1.8200000E+00 Y 5.6200000E+00 DELAY TIME 4.4831342E-06

DETONATION TIME FOR EACH ROW(J)

J

Z-VARIABLES

BBAR = 5.000E-01	CRATIO= 1.000E+04	CVIS =-1.000E+00	CYCMX = 2.000E+00	CYCPH3=-1.000E+00	DMIN = 1.000E+02	
DTMIN = 1.000E-11	EMIN = 1.000E+07	EMOB = 0.	FINAL = 4.000E-01	GAMMA = 0.	IEXTX = 0	
ICSTOP= 0	IGM = 0	IMAX = 60	INTEP = 0	IPCYCL= 0	IPLGBT= 0	
IPLGRT= 0	IPR = 100	I1 = 3	I2 = 53	JEXTY = 0	JMAX = 200	
KUNITP= 7	KUNITW= 7	LVISC = 1	MAPS = 1	MINX = 0	MAXX = 0	
MINY = 0	MAXY = 0	MADD = 0	NDUMP7= 1	NFRELP= 100	NMXCLS= 800	
NLINER= 1	NMAT = 2	NODUMP= 0	NOSLIP= 0	NSLD = 300	NTCC = 0	
NTPMX = 900	NTRACR= 5	NUMREZ= 0.	NUMSCA= 0	NVRTEX= 0		
PK(1) = 1.000E+00	PK(2) = 0.	PK(3) = 0.	PK(4) = 0.	PK(5) = 0.		
PLGOPT= 0.	PLYMIN= 0.	PMIN = 5.000E+06	PRCNT = 1.000E-03	PRDELT= 2.000E-06	PREACT= 0.	
PRLIM = 0.	PROB = 1.000E+00	REZ = 0.	PDEPS = 1.000E-05	SIEMIN= 1.000E+05	STAB = 1.000E-03	
TSTOP = 6.000E-06						

PACKAGE NUMBER	INITIAL DENSITY (RHOZ)	INITIAL DENSITY (RHOIN)	S.I.E.	U	V		MATERIAL
1	8.940	8.940	0.	0.	0.	G	COPPER
2	1.717	1.717	0.	0.	0.	J	COMP B

PACKAGE NUMBER	CZERO	STK1	STK2	STEZ	RMU	AMDM
1	2.350E+09	6.950E+10	5.500E+10	5.300E+09	4.550E+11	9.785E-01
2	0.	0.	0.	0.	0.	1.000E+00

I	DR	I	DR	I	DR	I	DR	I	DR	I	DR	I	DR
1	5.000E-02	2	5.000E-02	3	5.000E-02	4	5.000E-02	5	5.000E-02	6	5.000E-02	7	5.000E-02
8	5.000E-02	9	5.000E-02	10	5.000E-02	11	5.000E-02	12	5.000E-02	13	5.000E-02	14	5.000E-02
15	5.000E-02	16	5.000E-02	17	5.000E-02	18	5.000E-02	19	5.000E-02	20	5.000E-02	21	5.000E-02
22	5.000E-02	23	5.000E-02	24	5.000E-02	25	5.000E-02	26	5.000E-02	27	5.000E-02	28	5.000E-02
29	5.000E-02	30	5.000E-02	31	5.000E-02	32	5.000E-02	33	5.000E-02	34	5.000E-02	35	5.000E-02
36	5.000E-02	37	5.000E-02	38	5.000E-02	39	5.000E-02	40	5.000E-02	41	5.000E-02	42	5.000E-02
43	5.000E-02	44	5.000E-02	45	5.000E-02	46	5.000E-02	47	5.000E-02	48	5.000E-02	49	5.000E-02
50	5.000E-02	51	5.000E-02	52	5.000E-02	53	5.000E-02	54	5.000E-02	55	5.000E-02	56	5.000E-02
57	5.000E-02	58	5.000E-02	59	5.000E-02	60	5.000E-02						

I	R	I	R	I	R	I	R	I	R	I	R	I	R
1	5.000E-02	2	1.000E-01	3	1.500E-01	4	2.000E-01	5	2.500E-01	6	3.000E-01	7	3.500E-01
8	4.000E-01	9	4.500E-01	10	5.000E-01	11	5.500E-01	12	6.000E-01	13	6.500E-01	14	7.000E-01
15	7.500E-01	16	8.000E-01	17	8.500E-01	18	9.000E-01	19	9.500E-01	20	1.000E+00	21	1.050E+00
22	1.100E+00	23	1.150E+00	24	1.200E+00	25	1.250E+00	26	1.300E+00	27	1.350E+00	28	1.400E+00
29	1.450E+00	30	1.500E+00	31	1.550E+00	32	1.600E+00	33	1.650E+00	34	1.700E+00	35	1.750E+00
36	1.800E+00	37	1.850E+00	38	1.900E+00	39	1.950E+00	40	2.000E+00	41	2.050E+00	42	2.100E+00
43	2.150E+00	44	2.200E+00	45	2.250E+00	46	2.300E+00	47	2.350E+00	48	2.400E+00	49	2.450E+00
50	2.500E+00	51	2.550E+00	52	2.600E+00	53	2.650E+00	54	2.700E+00	55	2.750E+00	56	2.800E+00
57	2.850E+00	58	2.900E+00	59	2.950E+00	60	3.000E+00						

J	DZ	J	DZ	J	DZ	J	DZ	J	DZ	J	DZ	J	DZ
1	5.000E-02	2	5.000E-02	3	5.000E-02	4	5.000E-02	5	5.000E-02	6	5.000E-02	7	5.000E-02
8	5.000E-02	9	5.000E-02	10	5.000E-02	11	5.000E-02	12	5.000E-02	13	5.000E-02	14	5.000E-02
15	5.000E-02	16	5.000E-02	17	5.000E-02	18	5.000E-02	19	5.000E-02	20	5.000E-02	21	5.000E-02
22	5.000E-02	23	5.000E-02	24	5.000E-02	25	5.000E-02	26	5.000E-02	27	5.000E-02	28	5.000E-02
29	5.000E-02	30	5.000E-02	31	5.000E-02	32	5.000E-02	33	5.000E-02	34	5.000E-02	35	5.000E-02
36	5.000E-02	37	5.000E-02	38	5.000E-02	39	5.000E-02	40	5.000E-02	41	5.000E-02	42	5.000E-02
43	5.000E-02	44	5.000E-02	45	5.000E-02	46	5.000E-02	47	5.000E-02	48	5.000E-02	49	5.000E-02
50	5.000E-02	51	5.000E-02	52	5.000E-02	53	5.000E-02	54	5.000E-02	55	5.000E-02	56	5.000E-02
57	5.000E-02	58	5.000E-02	59	5.000E-02	60	5.000E-02	61	5.000E-02	62	5.000E-02	63	5.000E-02
64	5.000E-02	65	5.000E-02	66	5.000E-02	67	5.000E-02	68	5.000E-02	69	5.000E-02	70	5.000E-02
71	5.000E-02	72	5.000E-02	73	5.000E-02	74	5.000E-02	75	5.000E-02	76	5.000E-02	77	5.000E-02
78	5.000E-02	79	5.000E-02	80	5.000E-02	81	5.000E-02	82	5.000E-02	83	5.000E-02	84	5.000E-02
85	5.000E-02	86	5.000E-02	87	5.000E-02	88	5.000E-02	89	5.000E-02	90	5.000E-02	91	5.000E-02
92	5.000E-02	93	5.000E-02	94	5.000E-02	95	5.000E-02	96	5.000E-02	97	5.000E-02	98	5.000E-02
99	5.000E-02	100	5.000E-02	101	5.000E-02	102	5.000E-02	103	5.000E-02	104	5.000E-02	105	5.000E-02
106	5.000E-02	107	5.000E-02	108	5.000E-02	109	5.000E-02	110	5.000E-02	111	5.000E-02	112	5.000E-02
113	5.000E-02	114	5.000E-02	115	5.000E-02	116	5.000E-02	117	5.000E-02	118	5.000E-02	119	5.000E-02
120	5.000E-02	121	5.000E-02	122	5.000E-02	123	5.000E-02	124	5.000E-02	125	5.000E-02	126	5.000E-02
127	5.000E-02	128	5.000E-02	129	5.000E-02	130	5.000E-02	131	5.000E-02	132	5.000E-02	133	5.000E-02

190	5.000E-02	191	5.000E-02	192	5.000E-02	193	5.000E-02	194	5.000E-02	195	5.000E-02	196	5.000E-02		
197	5.000E-02	198	5.000E-02	199	5.000E-02	200	5.000E-02								

J	Z	J	Z	J	Z	J	Z	J	Z	J	Z	J	Z
1	5.000E-02	2	1.000E-01	3	1.500E-01	4	2.000E-01	5	2.500E-01	6	3.000E-01	7	3.500E-01
8	4.000E-01	9	4.500E-01	10	5.000E-01	11	5.500E-01	12	6.000E-01	13	6.500E-01	14	7.000E-01
15	7.500E-01	16	8.000E-01	17	8.500E-01	18	9.000E-01	19	9.500E-01	20	1.000E+00	21	1.050E+00
22	1.100E+00	23	1.150E+00	24	1.200E+00	25	1.250E+00	26	1.300E+00	27	1.350E+00	28	1.400E+00
29	1.450E+00	30	1.500E+00	31	1.550E+00	32	1.600E+00	33	1.650E+00	34	1.700E+00	35	1.750E+00
36	1.800E+00	37	1.850E+00	38	1.900E+00	39	1.950E+00	40	2.000E+00	41	2.050E+00	42	2.100E+00
43	2.150E+00	44	2.200E+00	45	2.250E+00	46	2.300E+00	47	2.350E+00	48	2.400E+00	49	2.450E+00
50	2.500E+00	51	2.550E+00	52	2.600E+00	53	2.650E+00	54	2.700E+00	55	2.750E+00	56	2.800E+00
57	2.850E+00	58	2.900E+00	59	2.950E+00	60	3.000E+00	61	3.050E+00	62	3.100E+00	63	3.150E+00
64	3.200E+00	65	3.250E+00	66	3.300E+00	67	3.350E+00	68	3.400E+00	69	3.450E+00	70	3.500E+00
71	3.550E+00	72	3.600E+00	73	3.650E+00	74	3.700E+00	75	3.750E+00	76	3.800E+00	77	3.850E+00
78	3.900E+00	79	3.950E+00	80	4.000E+00	81	4.050E+00	82	4.100E+00	83	4.150E+00	84	4.200E+00
85	4.250E+00	86	4.300E+00	87	4.350E+00	88	4.400E+00	89	4.450E+00	90	4.500E+00	91	4.550E+00
92	4.600E+00	93	4.650E+00	94	4.700E+00	95	4.750E+00	96	4.800E+00	97	4.850E+00	98	4.900E+00
99	4.950E+00	100	5.000E+00	101	5.050E+00	102	5.100E+00	103	5.150E+00	104	5.200E+00	105	5.250E+00
106	5.300E+00	107	5.350E+00	108	5.400E+00	109	5.450E+00	110	5.500E+00	111	5.550E+00	112	5.600E+00
113	5.650E+00	114	5.700E+00	115	5.750E+00	116	5.800E+00	117	5.850E+00	118	5.900E+00	119	5.950E+00
120	6.000E+00	121	6.050E+00	122	6.100E+00	123	6.150E+00	124	6.200E+00	125	6.250E+00	126	6.300E+00
127	6.350E+00	128	6.400E+00	129	6.450E+00	130	6.500E+00	131	6.550E+00	132	6.600E+00	133	6.650E+00
134	6.700E+00	135	6.750E+00	136	6.800E+00	137	6.850E+00	138	6.900E+00	139	6.950E+00	140	7.000E+00
141	7.050E+00	142	7.100E+00	143	7.150E+00	144	7.200E+00	145	7.250E+00	146	7.300E+00	147	7.350E+00
148	7.400E+00	149	7.450E+00	150	7.500E+00	151	7.550E+00	152	7.600E+00	153	7.650E+00	154	7.700E+00
155	7.750E+00	156	7.800E+00	157	7.850E+00	158	7.900E+00	159	7.950E+00	160	8.000E+00	161	8.050E+00
162	8.100E+00	163	8.150E+00	164	8.200E+00	165	8.250E+00	166	8.300E+00	167	8.350E+00	168	8.400E+00
169	8.450E+00	170	8.500E+00	171	8.550E+00	172	8.600E+00	173	8.650E+00	174	8.700E+00	175	8.750E+00
176	8.800E+00	177	8.850E+00	178	8.900E+00	179	8.950E+00	180	9.000E+00	181	9.050E+00	182	9.100E+00
183	9.150E+00	184	9.200E+00	185	9.250E+00	186	9.300E+00	187	9.350E+00	188	9.400E+00	189	9.450E+00
190	9.500E+00	191	9.550E+00	192	9.600E+00	193	9.650E+00	194	9.700E+00	195	9.750E+00	196	9.800E+00
197	9.850E+00	198	9.900E+00	199	9.950E+00	200	1.000E+01						

CYCLE 0

.6675217E+07ERGS HAS BEEN ADDED DUE TO DETONATION OF THESE CELLS@
1 51

CDT 1 51 T=3.6534786E-08 DT=1.0220935E-09 MAXCUV=9.7838408E+04 MAXUV=0. UMIN=9.7838408E-01 PMIN=5.0000000E+06

PROBLEM	TIME	CYCLE	TOT.EN.THEOR.	MAX.REL.ERROR-CYCLE	IE SET TO ZERO-PH2	ELASTIC PLASTIC WORK
1.0000	3.6534786E-08	0	6.6752169E+06	0. 0	0.	0.

PACKAGE NO.	IE	KE	TOT.EN. (SUM)	MASS	MV	MV(POSITIVE)	MU	PLASTIC-WORK
1	0.	0.	0.	2.1929690E+01	0.	0.	0.	0.
2	6.6752169E+06	0.	6.6752169E+06	7.0936117E+01	0.	0.	0.	0.
TOTALS	6.6752169E+06	0.	6.6752169E+06	9.2865807E+01	0.	0.	0.	0.

	IE OUT	KE OUT
1	0.	0.
2	0.	0.

BOUNDARY	BOTTOM	RIGHT	TOP	$EVAPORATED$
MASS OUT	0.	0.	0.	0.
ENERGY OUT	0.	0.	0.	0.
MU OUT	0.	0.	0.	0.
MV OUT	0.	0.	0.	0.
WORK DONE	0.	0.	0.	

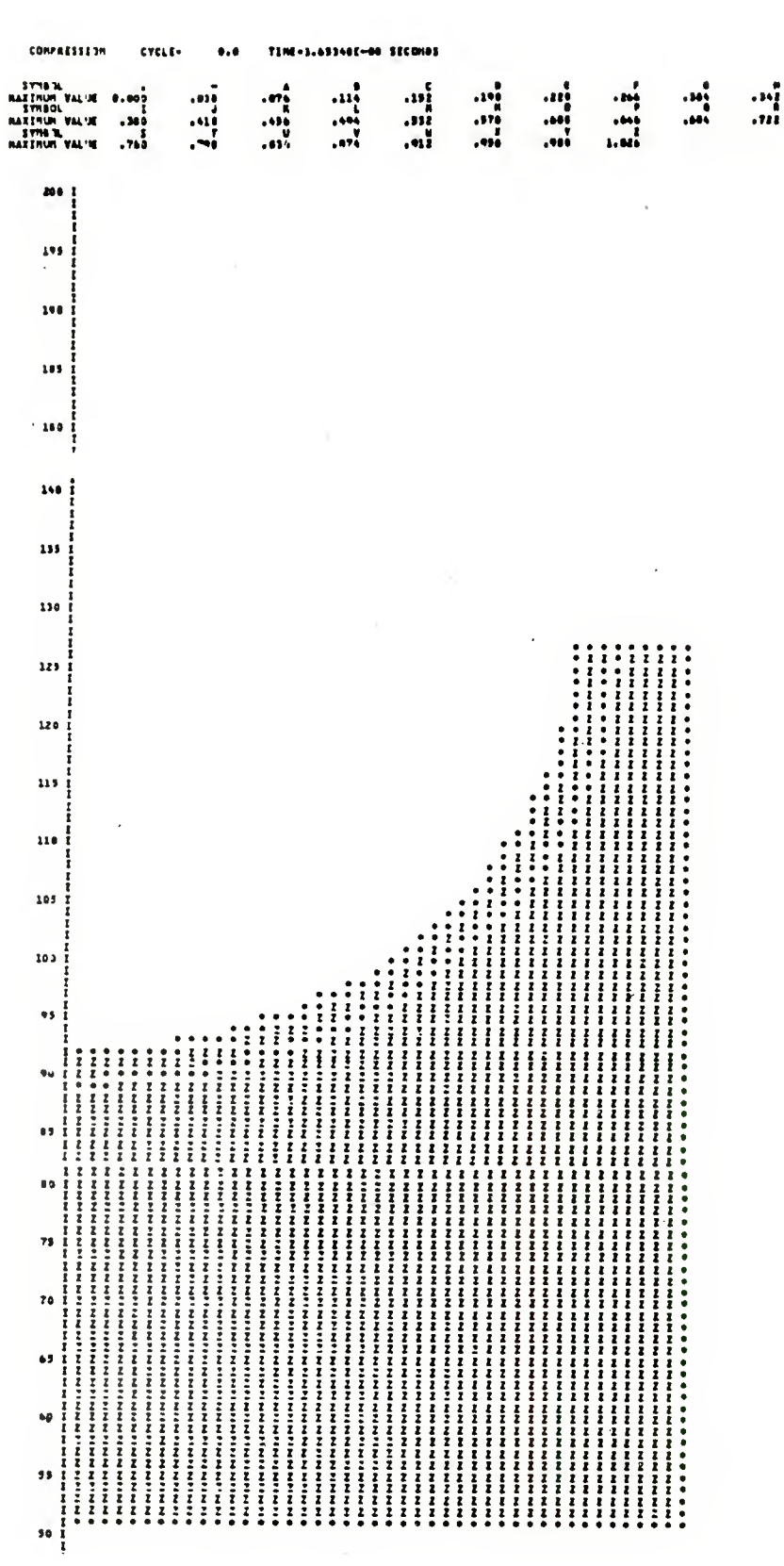
DEFINITION OF SLIDE ENDPOINTS

PKG. NO.	MASTER	SLAVE	NBGM	NBGS	NENDM	NENDS
1	1	0	1	0	300	0
2	0	2	0	301	0	600

CELL-COORDINATES OF TRACERS FOR EACH MATERIAL PACKAGE

PACKAGE 1

N	X	Y	N	X	Y	N	X	Y	N	X	Y	N	X	Y
1	0.00	88.90	2	.20	88.90	3	.40	88.90	4	.60	88.90	5	.80	88.91
6	1.00	88.91	7	1.20	88.92	8	1.40	88.93	9	1.60	88.93	10	1.80	88.94
11	2.00	88.95	12	2.20	88.96	13	2.40	88.98	14	2.60	88.99	15	2.80	89.00
16	3.00	89.02	17	3.20	89.03	18	3.40	89.05	19	3.60	89.07	20	3.80	89.09
21	4.00	89.11	22	4.19	89.13	23	4.39	89.15	24	4.59	89.18	25	4.79	89.20
26	4.99	89.23	27	5.19	89.25	28	5.39	89.28	29	5.58	89.31	30	5.78	89.34
31	5.98	89.37	32	6.18	89.40	33	6.38	89.44	34	6.57	89.47	35	6.77	89.51
36	6.97	89.54	37	7.16	89.58	38	7.36	89.62	39	7.56	89.66	40	7.75	89.70
41	7.95	89.74	42	8.14	89.78	43	8.34	89.82	44	8.53	89.87	45	8.73	89.91
46	8.92	89.96	47	9.12	90.01	48	9.31	90.06	49	9.51	90.10	50	9.70	90.16
51	9.89	90.21	52	10.09	90.26	53	10.28	90.31	54	10.47	90.37	55	10.66	90.42
56	10.86	90.48	57	11.05	90.54	58	11.24	90.60	59	11.43	90.66	60	11.62	90.72
61	11.81	90.78	62	12.00	90.84	63	12.19	90.90	64	12.38	90.97	65	12.57	91.03
66	12.76	91.10	67	12.95	91.17	68	13.14	91.24	69	13.32	91.31	70	13.51	91.38
71	13.70	91.45	72	13.88	91.52	73	14.07	91.59	74	14.26	91.67	75	14.44	91.74
76	14.63	91.82	77	14.81	91.90	78	15.00	91.98	79	15.18	92.05	80	15.36	92.13
81	15.55	92.22	82	15.73	92.30	83	15.91	92.38	84	16.09	92.46	85	16.27	92.55
86	16.45	92.64	87	16.63	92.72	88	16.81	92.81	89	16.99	92.90	90	17.17	92.99
91	17.35	93.08	92	17.53	93.17	93	17.71	93.26	94	17.88	93.36	95	18.06	93.45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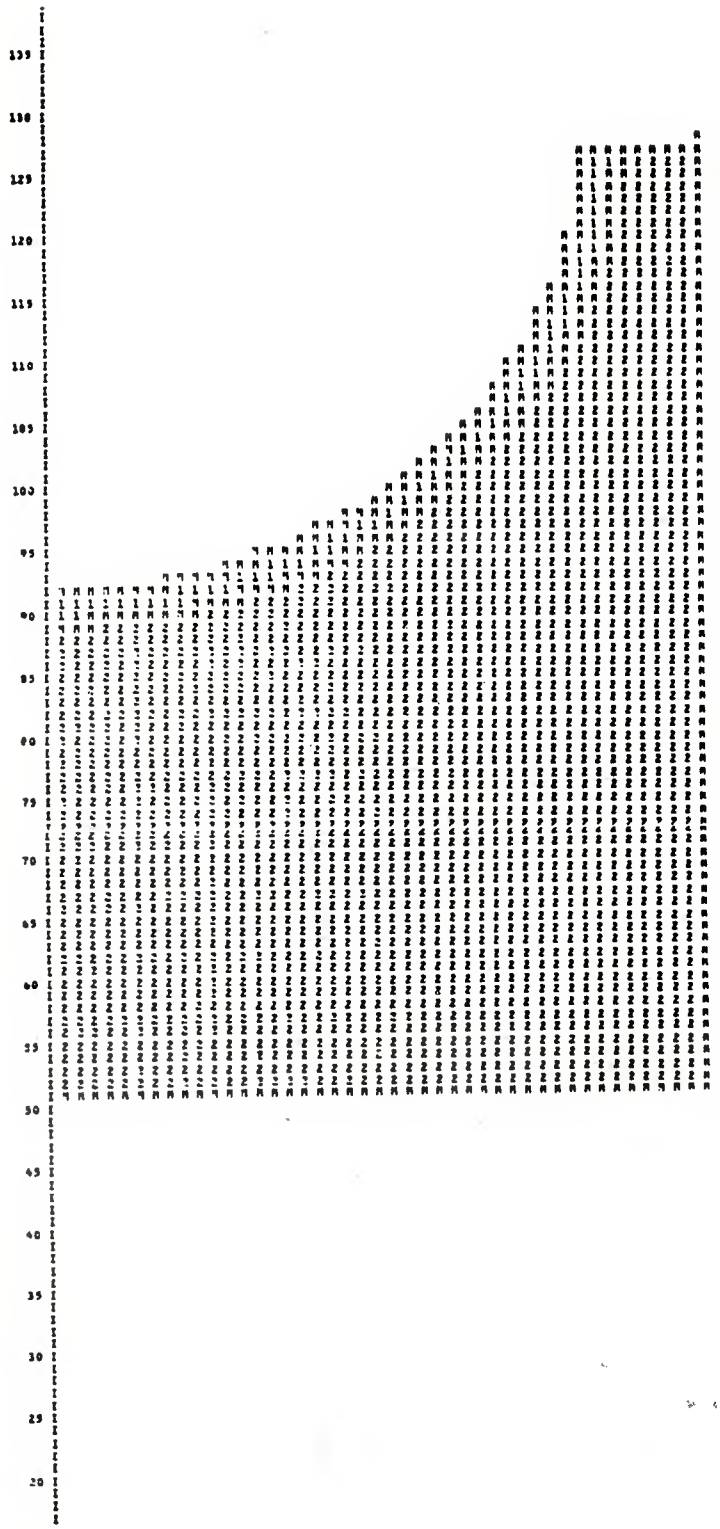
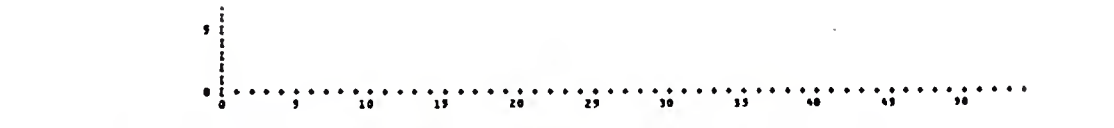
SYMBOL . - A B C D E F G H
MAXIMUM VALUE 0.000 .038 .076 .114 .152 .190 .228 .266 .304 .342
SYMBOL I J K L M N O P Q R
MAXIMUM VALUE .380 .418 .456 .494 .532 .570 .608 .646 .684 .722
SYMBOL S T U V W X Y Z
MAXIMUM VALUE .760 .798 .836 .874 .912 .950 .988 1.026



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 TPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERR=   0.
                                   EINTC=  6.67521690E+06      EINTM=  6.67521690E+06
                                   EKINC=  0.                  EKINM=  0.

 CYCLE    1

 CBT  1  91  T=3.7936889E-08  DT=2.0366609E-09  MAXCUV=9.8199969E+06  MAXUV=3.6156181E+02  UMIN=9.8199969E-01  PMIN=9.0000000E+06
 MPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERP=   0.
                                   EINTC=  6.67518196E+06      EINTM=  6.67518196E+06
                                   EKINC=  3.49368347E+01      EKINM=  3.49368347E+01
 TPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERP=   0.
                                   EINTC=  6.67518196E+06      EINTM=  6.67518196E+06
                                   EKINC=  3.49368347E+01      EKINM=  3.49368347E+01

 CYCLE    2

 CBT  1  91  T=3.8393549E-08  DT=4.0438242E-10  MAXCUV=9.8916268E+06  MAXUV=1.0781032E+03  UMIN=9.8916268E-01  PMIN=9.0000000E+06
 MPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERP=   4.4646223ZE-19
                                   EINTC=  6.67497736E+06      EINTM=  6.67497736E+06
                                   EKINC=  2.39533544E+02      EKINM=  2.39533544E+02
 TPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERR=   4.4646223ZE-19
                                   EINTC=  6.67497736E+06      EINTM=  6.67497736E+06
                                   EKINC=  2.39533544E+02      EKINM=  2.39533544E+02

 CYCLE    3

 CBT  1  91  T=4.3837365E-08  DT=7.9743126E-09  MAXCUV=1.0032213E+05  MAXUV=2.4853687E+03  UMIN=1.0032213E+00  PMIN=9.0000000E+06
 MPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERR=   4.4646223ZE-19
                                   EINTC=  6.67406728E+06      EINTM=  6.67406728E+06
                                   EKINC=  1.14961688E+03      EKINM=  1.14961688E+03
 TPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERR=   4.4646223ZE-19
                                   EINTC=  6.67406728E+06      EINTM=  6.67406728E+06
                                   EKINC=  1.14961688E+03      EKINM=  1.14961688E+03

 CYCLE    4

 CBT  1  91  T=5.1611677E-08  DT=1.9529287E-08  MAXCUV=1.0303113E+05  MAXUV=9.2807302E+03  UMIN=1.0303113E+00  PMIN=9.0000000E+06
 MPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERR=   0.
                                   EINTC=  6.67051644E+06      EINTM=  6.67051644E+06
                                   EKINC=  4.70040920E+03      EKINM=  4.70040920E+03
 TPHASE   ET=   6.67521690E+06      ESUM=   6.67521690E+06      EMIX=   6.67521690E+06      RELERP=   0.
                                   EINTC=  6.67051644E+06      EINTM=  6.67051644E+06
                                   EKINC=  4.70040920E+03      EKINM=  4.70040920E+03

 CYCLE    5
 .333743AE+0BERGS WAS BEEN ADDED DUE TO DETONATION OF THESE CELLSB
                          1       52

 CBT  1  92  T=6.7140964E-08  DT=7.3953358E-09  MAXCUV=4.3278516E+05  MAXUV=1.0263647E+04  UMIN=4.3278516E+00  PMIN=9.0000000E+06
 MPHASE   ET=   4.00513014E+07      ESUM=   4.00513014E+07      EMIX=   4.00513014E+07      RELERP=   0.
                                   EINTC=  4.00433412E+07      EINTM=  4.00433412E+07
                                   EKINC=  7.76015068E+03      EKINM=  7.76015068E+03
 TPHASE   ET=   4.00513014E+07      ESUM=   4.00513014E+07      EMIX=   4.00513014E+07      RELERP=  -5.9928297TE-19
                                   EINTC=  4.00433412E+07      EINTM=  4.00433412E+07
                                   EKINC=  7.76015068E+03      EKINM=  7.76015068E+03

 CYCLE    6

 CBT  1  92  T=7.4334303E-08  DT=1.4497159E-08  MAXCUV=4.4268731E+05  MAXUV=1.2467252E+04  UMIN=4.4268731E+00  PMIN=9.0000000E+06
 MPHASE   ET=   4.00513014E+07      ESUM=   4.00513014E+07      EMIX=   4.00513014E+07      RELERR=  -5.9928297TE-19
                                   EINTC=  3.98762332E+07      EINTM=  3.98762332E+07
                                   EKINC=  1.79068148E+03      EKINM=  1.79068148E+03
```

PROBLEM	TIME	CYCLE	TOT.EN.THEOR.	MAX.REL.ERROR-CYCLE		IE SET TO ZERO-PH2	ELASTIC PLASTIC WORK
1.0000	2.0000000E-06	69	7.2261894E+11	5.9502875E-14	66	5.0062888E+03	0.

PACKAGE NO.	IE	KE	TOT.EN. (SUM)	MASS	MV	MV(POSITIVE)	MU	PLASTIC-WORK
1	0.	0.	0.	2.1929690E+01	0.	0.	0.	0.
2	7.1394745E+11	8.6714097E+09	7.2261894E+11	7.0936117E+01	-1.2940632E-08	4.9823115E+05	7.6537133E+05	0.
TOTALS	7.1394745E+11	8.6714097E+09	7.2261894E+11	9.2865807E+01	-1.2940632E-08	4.9823115E+05	7.6537133E+05	0.

	IE OUT	KE OUT
1	0.	0.
2	-5.0062888E+03	0.

BOUNDARY	BOTTOM	RIGHT	TOP	$EVAPORATED$
MASS OUT	0.	0.	0.	0.
ENERGY OUT	0.	0.	0.	0.
MU OUT	0.	0.	0.	0.
MV OUT	0.	0.	0.	0.
WORK DONE	0.	0.	0.	

TAPE 7 DUMP ON CYCLE 69

DEFINITION OF SLIDE ENDPOINTS

PKG. NO.	MASTER	SLAVE	MBGN	MBGS	MENDN	MENDS
1	1	0	1	0	300	0
2	0	2	0	301	0	600

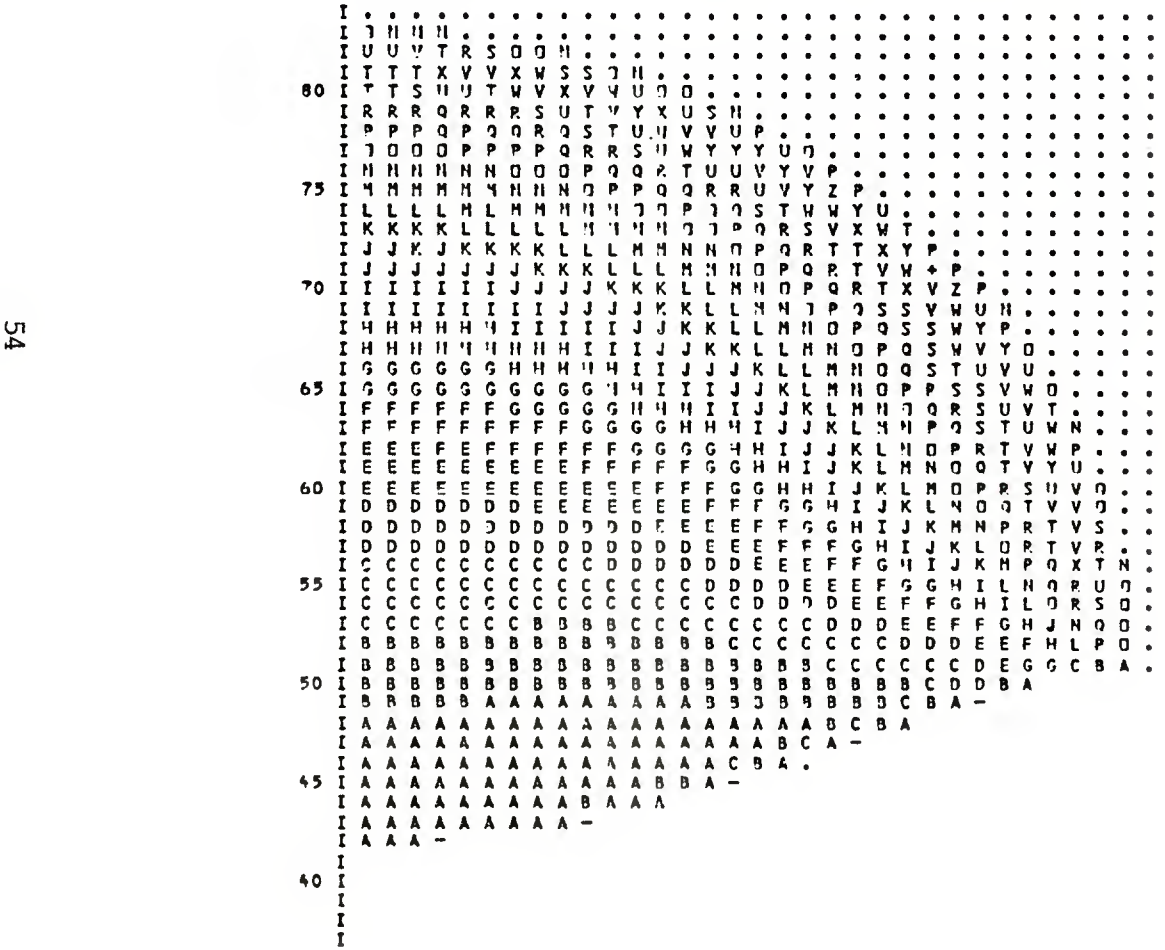
CELL-COORDINATES OF TRACERS FOR EACH MATERIAL PACKAGE

PACKAGE 1

N	X	Y	N	X	Y	N	X	Y	N	X	Y	N	X	Y
1	0.00	88.90	2	.20	88.90	3	.40	88.90	4	.60	88.90	5	.80	88.91
6	1.00	88.91	7	1.20	88.92	8	1.40	88.93	9	1.60	88.93	10	1.80	88.94
11	2.00	88.95	12	2.20	88.96	13	2.40	88.98	14	2.60	88.99	15	2.80	89.00
16	3.00	89.02	17	3.20	89.03	18	3.40	89.05	19	3.60	89.07	20	3.80	89.09
21	4.00	89.11	22	4.19	89.13	23	4.39	89.15	24	4.59	89.18	25	4.79	89.20
26	4.99	89.23	27	5.19	89.25	28	5.39	89.28	29	5.58	89.31	30	5.78	89.34
31	5.98	89.37	32	6.19	89.40	33	6.38	89.44	34	6.57	89.47	35	6.77	89.51
36	6.97	89.54	37	7.14	89.58	38	7.36	89.62	39	7.56	89.66	40	7.75	89.70
41	7.95	89.74	42	8.14	89.78	43	8.34	89.82	44	8.53	89.87	45	8.73	89.91
46	8.92	89.96	47	9.12	90.01	48	9.31	90.06	49	9.51	90.10	50	9.70	90.16

PRESSURE CYCLE= 69.0 TIME=2.00000E-06 SECONDS

SYMBOL	.	-	A	B	C	D	E	F	G	H
MAXIMUM VALUE	0.	8.83E+08	8.83E+09	1.77E+10	2.65E+10	3.53E+10	4.42E+10	5.30E+10	6.18E+10	7.07E+10
SYMBOL	I	J	K	L	M	N	O	P	Q	R
MAXIMUM VALUE	7.95E+10	8.83E+10	9.72E+10	1.06E+11	1.15E+11	1.24E+11	1.33E+11	1.41E+11	1.50E+11	1.59E+11
SYMBOL	S	T	U	V	W	X	Y	Z		
MAXIMUM VALUE	1.68E+11	1.77E+11	1.86E+11	1.94E+11	2.03E+11	2.12E+11	2.21E+11	2.30E+11		



ESTCON

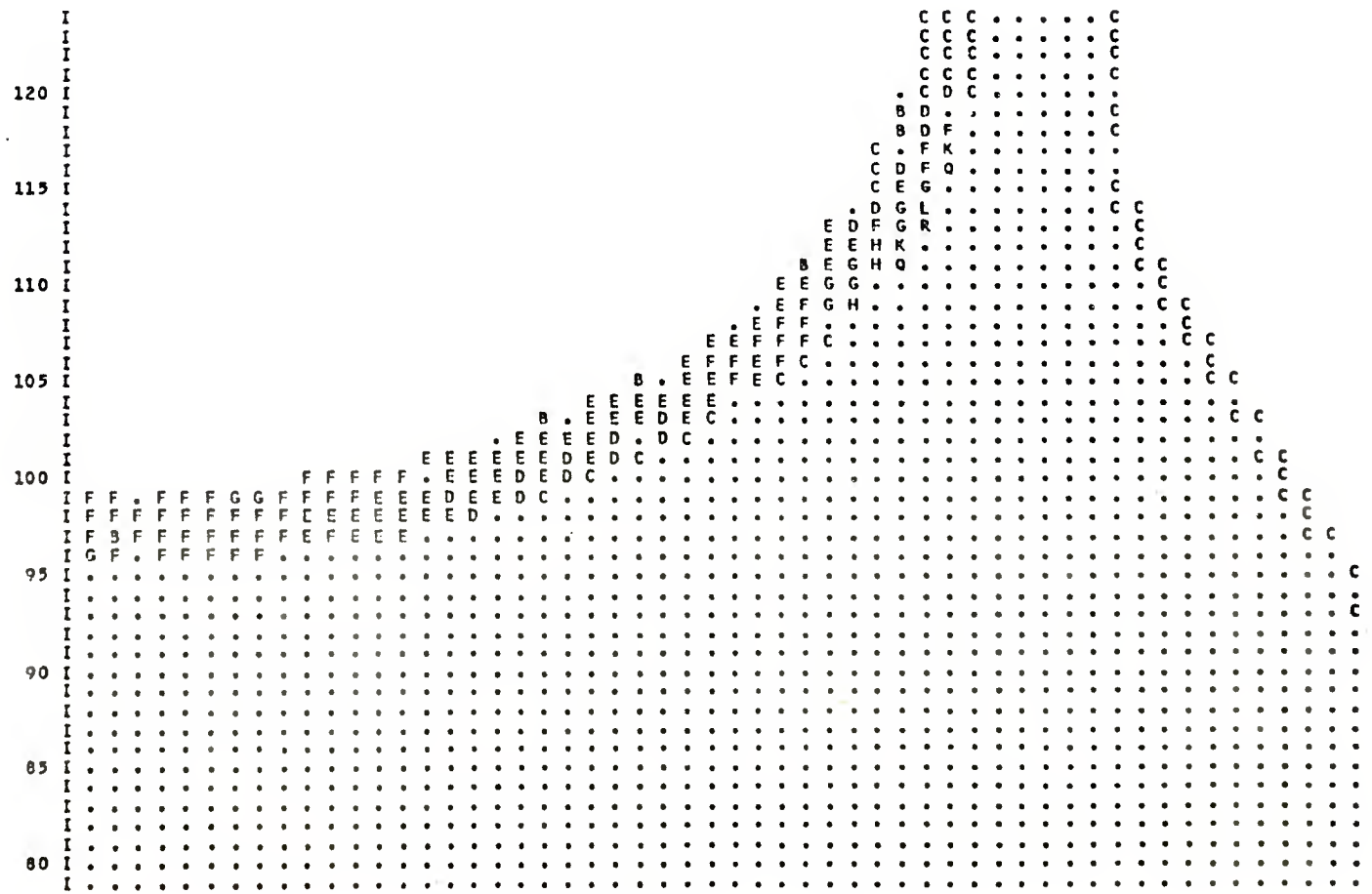
8.940000E+00	0.	0.	0.	0.
3.940000E+05	0.	0.	0.	5.370000E+10
4.790000E+10	6.671000E+09	4.621000E+09	1.200000E-01	1.600000E-01
1.490000E+00	1.970000E+00	1.500000E+00	6.667000E-01	4.900000E-09
1.790000E+03	0.	0.	6.354000E+01	4.470000E-01
5.600000E-02	3.500000E+01	1.140700E+04	9.637000E-05	0.

ECONS

1.118568E-01	7.711678E-11	1.516682E-06	1.830343E-07	1.282138E-06
5.787367E-01	4.043368E-05	1.410627E+03	1.841302E+02	1.685342E-05
-6.324087E-04	-7.280000E-02	0.	3.580300E+03	1.048412E-01
1.336743E-01	8.669092E-03	8.230059E-02	-1.044954E-06	8.756600E-10

TEMPERATURE CYCLE= 175.0 TIME=4.95639E-06 SECONDS

SYMBOL	.	-	A	B	C	D	E	F	G	H
MAXIMUM VALUE	0.	1.04E+01	1.04E+02	2.08E+02	3.12E+02	4.16E+02	5.20E+02	6.24E+02	7.28E+02	8.32E+02
SYMBOL	I	J	K	L	M	N	O	P	Q	R
MAXIMUM VALUE	9.36E+02	1.04E+03	1.14E+03	1.25E+03	1.35E+03	1.46E+03	1.56E+03	1.66E+03	1.77E+03	1.87E+03
SYMBOL	S	T	U	V	W	X	Y	Z		
MAXIMUM VALUE	1.98E+03	2.08E+03	2.18E+03	2.29E+03	2.39E+03	2.50E+03	2.60E+03	2.70E+03		



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